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27 March 1973
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3 May 1971

MILITARY STANDARD

MAINTAINABILITY VERIFICATION/DEMONSTRATION/EVALUATION

MISC-0855

MILITARY STANDARD

MAINTAINABILITY VERIFICATION/DEMONSTRATION/EVALUATION

TO ALL HOLDERS OF MIL-STD-471A

1. The following are new and revised pages of this standard. The revised pages supersede the original pages:

NEW PAGE	DATE	SUPERSEDED PAGE	DATE
iii	27 March 1973 (Reprinted without change)		
iv	10 January 1975	iv	27 March 1973
19	10 January 1975	19	27 March 1973
20	10 January 1975	20	27 March 1973
21	10 January 1975	21	27 March 1973
22	10 January 1975	22	27 March 1973
25	27 March 1973 (Reprinted without change)		
26	10 January 1975	26	27 March 1973
26a	10 January 1975	New Page	
27	10 January 1975	27	27 March 1973
27a	10 January 1975	New Page	
28	27 March 1973 (Reprinted without change)		
29	27 March 1973 (Reprinted without change)		
30	10 January 1975	30	27 March 1973
30a	10 January 1975	New Page	
31	10 January 1975	31	27 March 1973
32	10 January 1975	32	27 March 1973
33a	27 March 1973 (Reprinted without change)		
34	10 January 1975	34	27 March 1973
35	10 January 1975	35	27 March 1973
36	27 March 1973 (Reprinted without change)		
37	10 January 1975	37	27 March 1973
38	27 March 1973 (Reprinted without change)		
41	10 January 1975	41	27 March 1973
42	10 January 1975	42	27 March 1973
43	10 January 1975	43	27 March 1973
44	27 March 1973 (Reprinted without change)		
55-77	10 January 1975	New Pages	

2. RETAIN THIS NOTICE PAGE AND INSERT BEFORE THE TABLE OF CONTENTS.

FSC - MISC

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Preparing Activity:
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MIL-STD-471A
27 March 1973

DEPARTMENT OF DEFENSE
WASHINGTON DC

MAINTAINABILITY VERIFICATION/DEMONSTRATION/EVALUATION
MIL-STD-471A

1. This standard is approved for use by all Departments and Agencies of the Department of Defense.

2. Recommended corrections, additions, or deletions should be reported to the preparing activity (see Defense Standardization Directory SD-1 for mailing address).

FOREWORD

Maintainability, a characteristic of design and installation and affected by various personnel and logistic factors, is one of many system requirements which must be considered during the system engineering effort. The degree of maintainability achieved depends upon the requirements imposed and management emphasis on maintainability. This standard defines a carefully planned program to be implemented for verification, demonstration and evaluation of maintainability.

The purpose of this standard is to establish uniform procedures, test methods, and requirements for verification, demonstration, and evaluation of the achievement of specified maintainability requirements and for assessment of the impact of planned logistic support.

This standard is applicable to all Department of Defense procurements which require a maintainability verification/demonstration/evaluation of maintainability requirements.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

Supersedes page iv of 27 March 1973

1. SCOPE

1.1 Purpose. This standard provides procedures and test methods for verification, demonstration, and evaluation of qualitative and quantitative maintainability requirements. It also provides for qualitative assessment of various integrated logistic support factors related to and impacting the achievement of maintainability parameters and item downtime, e.g., technical manuals, personnel, tools and test equipment, maintenance concepts and provisioning.

1.2 Application. The standard is intended for use when verification, demonstration, and evaluation of maintainability requirements for hardware procurements is required. The verification, demonstration, and evaluation of achievement of maintainability requirements shall normally be conducted in three (3) phases, as described in Section 4, and in conjunction with verification, demonstration, and evaluation of the requirements for total Integrated Logistic Support. Exceptions to the three phases shall be as specified by the procuring activity.

2. APPLICABLE DOCUMENTS

The issues of the following documents in effect on the date of invitation for bids or request for proposal form a part of this standard to the extent specified herein:

STANDARDS

MILITARY

MIL-STD-280 Definitions of Item Levels, Item Exchangeability, Models, and Related Terms

MIL-STD-470 Maintainability Program Requirements (For Systems and Equipments)

MIL-STD-721 Definition of Effectiveness Terms for Reliability, Maintainability, Human Factors, and Safety

"Copies of specifications, standards, drawings and publications required by suppliers in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer."

3. DEFINITIONS

Meanings of terms not defined herein are in accordance with MIL-STD-280 and MIL-STD-721.

3.1 Maintenance Task. The maintenance effort necessary for retaining an item in, changing to, or restoring it to a specified condition. The procuring activity will provide to the contractor any terms that will be considered synonomous with the term task and will provide definitive criteria for determining different types of maintenance tasks and the timing of the tasks during verification/demonstration/evaluation.

3.2 Maintainability Model. A quantifiable representation of a test or process the purpose of which is to analyze results to determine specific relationships of a set of quantifiable maintainability parameters.

3.3 Verification. The contractor effort, monitored by the procuring activity, from date of award of the contract, progressing concurrently through hardware development from components to the configuration item (CI); to determine the accuracy of and update the analytical (predicted) data obtained from the maintainability engineering analysis; to identify maintainability design deficiencies; and to gain progressive assurance that the maintainability of the item can be achieved and demonstrated in subsequent phases.

3.4 Demonstration. The joint contractor and procuring activity effort to determine whether specified maintainability contractual requirements have been achieved.

3.5 Evaluation. The procuring activity effort to determine, at all levels of maintenance, the impact of the operational, maintenance and support environment on the maintainability parameters of the item and to demonstrate depot level maintenance tasks.

3.6 Development Test and Evaluation (DT&E). Test and evaluation which focuses on the technological and engineering aspects of the system, subsystem, or equipment items.

3.7 Operational Test and Evaluation (OT&E). Test and evaluation which focuses on the development of optimum tactics, techniques, procedures, and concepts for systems and equipment, evaluation of reliability, maintainability and operational effectiveness, and suitability of systems and equipment under realistic operational conditions.

3.8 Maintenance Concept. A description of the planned general scheme for maintenance and support of an item in the operational environment.

3.9 Maintenance Environment. The climatic, geographical, physical and operational conditions (e.g., combat, mobil, continental) under which an item will be maintained.

4. REQUIREMENTS

4.1 General. Maintainability (M) verification, demonstration, and evaluation shall be performed in accordance with the M test plan (see 4.2) prepared by the contractor and approved by the procuring activity. The M test plan shall form a part of the integrated support plan when an integrated support plan is required. The M test plan shall be prepared and submitted as part of the contractor's proposal, and progressively updated as design, development, and fabrication proceed. It shall be available for in process review by the procuring activity. Those portions of the total M test plan applicable to specific phases (verification, demonstration, evaluation) shall be submitted to the procuring activity for approval prior to its implementation and no later than the date specified by the contract. The M test plan shall be totally responsive to the qualitative and quantitative requirements and supplemental information contained in the procurement documents and the M program plan required by MIL-STD-470, "Maintainability Program Requirements." The supplemental information shall include, but not be limited to, maintenance concept, maintenance environment, skill levels of personnel, level(s) of maintenance to be demonstrated, and modes of operation for test, including configuration and missions. Coordination of the M verification, demonstration, and evaluation with other required demonstrations shall be accomplished whenever possible to avoid unnecessary duplication of effort. The environment and procedures shall represent, as closely as practical, that which can be expected in the intended operational use of the item. The plan, when applied to the system level, shall embody the three (3) phases: verification (Phase I); demonstration (Phase II); and evaluation (Phase III). When the plan is applied to less than system level, the procuring activity shall specify the applicable phases. Figure 1 depicts a general time-phase relationship of the three (3) phases. It should be recognized that Figure 1 depicts a general time-phasing only, which may differ for individual procurements. The procuring activity will provide guidance to the contractor as to the relationship between system life cycle phases and the verification/demonstration/evaluation phases. Of particular importance to the accomplishment of the procedures contained in this standard is the detailed information contained in the contractor's maintainability analysis as defined in MIL-STD-470. This analysis must contain a comprehensive description of the predicted maintenance tasks. For example, the maintainability analysis shall contain the following:

a. Failure mode or symptom and "how malfunction code," which would initiate the corrective maintenance task.

b. Frequency of occurrence of each failure mode and symptom of every maintenance task.

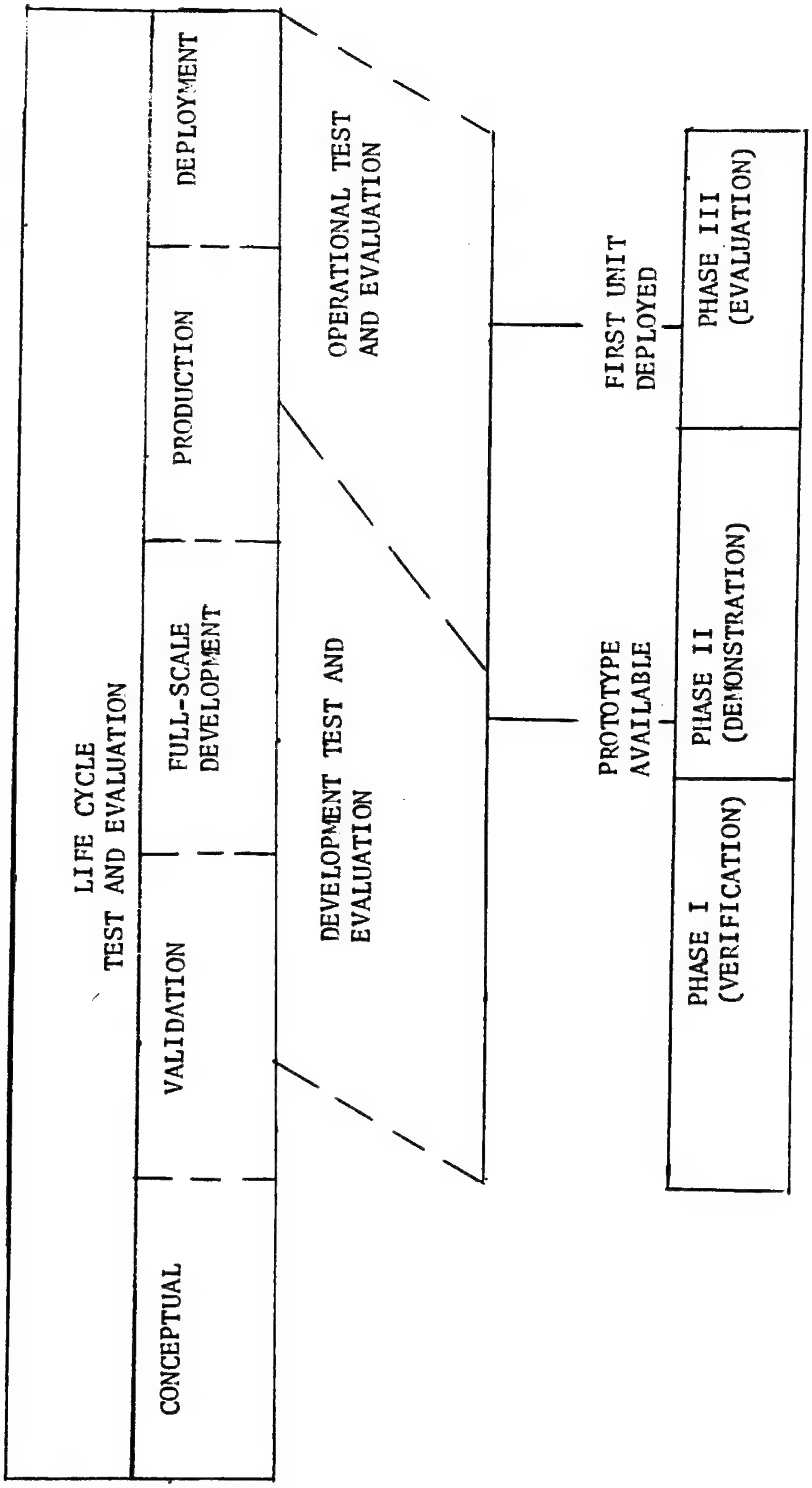


FIG. 1 - TIME PHASED CHART FOR MAINTAINABILITY VERIFICATION/DEMONSTRATION/EVALUATION

c. Appropriate "action taken codes" and "work unit codes" for each maintenance task.

d. Predicted times for each element of maintenance time as defined in MIL-STD-721.

e. Skill levels and number of people required for each maintenance task.

f. Support equipment and tools required for each maintenance task.

g. Technical order interface for each maintenance task.

h. Identification of preventive maintenance tasks.

i. Identification of those maintenance tasks which are not normally or under any circumstances will not be permitted to be performed concurrently with other maintenance tasks. It is assumed that all other maintenance tasks can be performed unrestricted by the performance of on-going maintenance.

4.1.1 Phase I. During Phase I, the contractor shall conduct an incremental verification effort, commencing with initial design and continuing through hardware development from components to the configuration item. The basic objectives of this phase are:

4.1.1.1 To verify and update the contractor's maintainability model.

4.1.1.2 To insure economical correction of design deficiencies and to provide assurance that maintainability requirements will be achieved and demonstrated, by performing early in the design process, M verifications such as limited low confidence maintainability tests, time-motion measurements or such other tests as may be proposed by the contractor, subject to approval by the procuring activity.

4.1.1.3 To provide progressive assurance that the maintainability requirements can be achieved and demonstrated and that elements of the integrated support plan directly related to M are valid.

Maximum use shall be made of data resulting from maintenance performed in conjunction with such tests as development, prototype, mock-up, qualification, and reliability tests. When the procurement documents specify that the maintainability demonstration shall be part of Phase I, the M demonstration and requirements of Phase II (see 4.1.2) shall apply.

4.1.2 Phase II. The objective of this phase is to determine during Development, Test and Evaluation (D, T&E) whether all specified $\bar{M}$ contractual requirements, except as noted under Phase III have been achieved. During this phase, the procuring activity will manage and conduct a maintainability demonstration as part of the total system demonstration. For those procurements which do not require a total system demonstration, the maintainability demonstration to be conducted during Phase II shall be an extension of Phase I. To assure acceptability of recorded data and resultant analysis, the contractor shall participate to the extent provided in 4.4 of this standard. The following requirements apply to all maintainability demonstrations. Additional requirements or changes may be imposed on individual procurements.

4.1.2.1 The maintainability demonstration shall be conducted in an environment which simulates, as closely as practicable, the operational and maintenance environment planned for the item. This environment shall be representative of the working conditions, tools, support equipment, spares, facilities, and technical publications that would be required during operational service use at the maintenance level defined in the approved maintenance plan.

4.1.2.2 Government personnel assigned to the test organization shall operate and maintain the demonstration items (see 4.2.3 and 4.4.1). When demonstration is conducted as an extension of Phase I, the procuring activity shall specify the personnel (Government or contractor) who will operate and maintain the items.

4.1.2.3 In conjunction with the maintainability demonstration, the approved integrated support plan, when required, and established by the contractor, scaled to the number of test items employed in the demonstration, shall be implemented by the test team to identify the logistic support provided during Phase II.

4.1.2.4 All maintenance data, including depot level, shall be recorded and reported to the test team as specified by the procuring activity.

4.1.2.5 Unless approved otherwise by the procuring activity, the configuration of the items of the system selected for $\bar{M}$ demonstration shall be documented and certified by a physical configuration audit (PCA).

4.1.2.6 Unless approved otherwise by the procuring activity, all support equipment used during the demonstration shall be certified by PCA.

4.1.2.7 Maintenance tasks which may require fault simulation (see 4.3.1.2 and 4.3.1.3) shall require that the item be checked for normal operation prior to failure simulation and after completion of the

specified maintenance task. Whan a failure is simulated, it will be the responsibility of the test team to select the maintenance task, the failure to be simulated, and the failure mode; and to verify that the degree of failure is representative of the maintenance task to be demonstrated. The work area in which parts degradation or failure has been simulated shall contain no obvious evidence other than that normally resulting from the simulated mode of failure. The appearance of defective parts that are substituted for serviceable parts shall be that of a normally failed part. The technician shall not witness any fault insertion. Simulation of failures by introduction of faulty parts will not be used when the normal procedures could result in extensive damage to the equipment or item being tested. Each defective part is to be installed in the equipment in the same manner as the original part.

4.1.2.8 For maintenance tasks, whose faults have been simulated, the presence of necessary spares, tools, test and support equipment, or technical publications shall not assist in fault isolation by prematurely identifying the work to be done. Such items shall be covered or otherwise kept out of sight from the technician. However, simulated discrepancy data shall be made available, if applicable.

4.1.2.9 Maintenance personnel performing maintenance tasks for the demonstration shall be military or civil service personnel, with the exception that contractor personnel will perform those tasks specified to be performed by contractual personnel during the operational service use (see 4.1.2.2). Technicians shall have received the training and be of the equivalent skill level as specified in the standard personnel resource documentation for the specified level of maintenance. Exception to the training and skill level requirements may be made for specified tasks which will be performed by contractor personnel during operational service use.

4.1.2.10 Each maintenance task will be documented by personnel designated by the test team. The total time measured for a technician to perform each maintenance task shall be recorded and will include the time to perform each element of maintenance time defined in MIL-STD-721. Each element will be documented separately. The total delay time for each maintenance task shall be documented. The test plan and procedures shall include delay time rules.

4.1.2.11 The time required to obtain support items (appropriate test and support equipment, tools, spare parts, technical publications, etc.) from the defined work center area shall be recorded. This time shall not, however, be chargeable as maintenance task time for the item being demonstrated unless this time is controlled or influenced by the design of the item being demonstrated.

4.1.2.12 Items to be furnished by the contractor shall be provided in the type, quality, and quantity required for planned operation requirements scaled to the demonstration and evaluation requirements, prior to the start of the phase being performed. Items to be furnished by the procuring activity shall be identified and requested by the contractor in time to be available prior to the start of the phase being performed.

4.1.3 Phase III. The objective of this phase is to (1) evaluate the impact of the actual operational, maintenance, and support environment on the maintainability parameters of the system, (2) to evaluate the correction of deficiencies exhibited during Phase II, and (3) to demonstrate depot level maintenance tasks when applicable. A maintainability evaluation will be managed and conducted, by the procuring activity, during Operational, Test and Evaluation as part of the total system evaluation. To assure acceptability of recorded data and resultant analysis, the contractor shall participate in Phase III to the extent described in 4.4 of this standard or as otherwise provided. The same conditions outlined for Phase II (see 4.1.2) shall apply, except for the following:

4.1.3.1 All evaluation items shall be production or production equivalent models.

4.1.3.2 The evaluation shall be conducted in the actual operational and maintenance environment unless otherwise directed by the procuring activity.

4.1.3.3 All maintenance tasks will be accomplished by military or civil service personnel with the exception that contractor personnel will perform those tasks specified to be performed by contractual personnel during operational service use.

4.1.3.4 Depot level maintenance tasks shall be demonstrated and the data collected applied to the maintainability demonstration and evaluation.

4.1.3.5 Maintenance tasks to be evaluated shall be those resulting directly from and incidental to actual operation and maintenance. These tasks shall be supplemented by fault simulation only to evaluate specific tasks or special tasks (see 4.3.1.3) that do not occur by chance during the evaluation phase.

4.2 Maintainability Verification/Demonstration/Evaluation Plan. The plan, prepared by the contractor in accordance with the Contract Data Requirements List (CDRL), shall include the following sections, as a minimum,

identified with each of the three (3) phases, unless instructions to the contrary are provided in the specific procurement. Certain sections cover material subject to other, more specific, contractual requirements and may be included in the plan as they are prepared in response thereto. They are included to insure adequate attention and continuity.

4.2.1 Background Information. A description of:

4.2.1.1 Quantitative and qualitative maintainability requirements;

4.2.1.2 Maintenance concept;

4.2.1.3 Maintenance environment;

4.2.1.4 Level(s) of maintenance;

4.2.1.5 Sites;

4.2.1.6 Facilities' requirements;

4.2.1.7 Participating agencies;

4.2.1.8 Mode(s) of operation of the items, including configuration and mission requirements;

4.2.1.9 Items subject to verification, demonstration and evaluation; and

4.2.1.10 Contractual data required for completion of the verification/demonstration/evaluation.

4.2.2 Item Interfaces. A description of the adequacy or inadequacies of the item support elements and an estimate of their effect on the item maintainability. These elements would include the following:

4.2.2.1 Maintenance planning;

4.2.2.2 Support and test equipment;

4.2.2.3 Supply support;

4.2.2.4 Transportation, handling and storage;

4.2.2.5 Technical data;

4.2.2.6 Facilities; and

4.2.2.7 Personnel and training.

4.2.3 Test Team. A description of:

4.2.3.1 Organization;

4.2.3.2 Degree of contractor and procuring activity participation, including managerial, technical, maintenance, and operation personnel;

4.2.3.3 Assignment of specific responsibilities; and

4.2.3.4 Qualifications, quantity, sources, training, and indoctrination requirements for the test team personnel.

4.2.4 Support Material. A description of:

4.2.4.1 Support equipment;

4.2.4.2 Tools and test equipment;

4.2.4.3 Technical manuals;

4.2.4.4 Spares and consumables;

4.2.4.5 Safety equipment; and

4.2.4.6 Calibration equipment.

4.2.5 Preparation Stage. A description of and schedule for:

4.2.5.1 Organization and assembly of the test team;

4.2.5.2 Training of personnel;

4.2.5.3 Preparation of facilities; and

4.2.5.4 Availability, assembly, checkout, and preliminary validation of support material.

4.2.6 Verification/Demonstration/Evaluation Stage. A description of:

4.2.6.1 Test objectives;

4.2.6.2 Schedule of tests;

4.2.6.3 Procedure for selection of maintenance tasks when faults are simulated (see 4.3.1.2);

4.2.6.4 Identification of special maintenance tasks (see 4.3.1.3);

4.2.6.5 Test method, including accept/reject decision criteria, risks, etc.;

4.2.6.6 Data acquisition method;

4.2.6.7 Data analysis methods and procedures;

4.2.6.8 Specific data elements;

4.2.6.9 Units of measurement;

4.2.6.10 Type and schedule of reports;

4.2.6.11 Schedule of maintenance task accomplishment such as time change compliance tasks, inspection, lubrication, and turn around tasks; and

4.2.6.12 The maintenance tasks, other than those listed in 4.2.6.11, to be verified, demonstrated, and evaluated. These tasks may be prepared and submitted in a referenced document.

4.2.7 Retest Stage. A provisional schedule for special or repeat tests to investigate deficiencies or trouble areas. Deficiencies shall be corrected in any item which has failed to meet the acceptance criteria. The corrected portions of the item and any other portions of the item affected by the correction shall be retested during this stage. The maintenance tasks to be demonstrated shall be as designated by the procuring activity.

4.3 Test Procedures. In designing the maintainability test procedures, both qualitative and quantitative requirements shall be verified, demonstrated, and evaluated. Unless instructions to the contrary are provided in the specific procurement contractual documentation, qualitative maintainability requirements will be verified, demonstrated, and evaluated using contractor prepared checklists. These checklists, to be approved by the procuring activity, will permit observation, analysis, and identification of maintainability characteristics incorporated or omitted. Quantitative requirements shall be verified, demonstrated, and evaluated by actual demonstration of maintenance tasks.

4.3.1 Maintenance Task Generation. All maintenance tasks shall be performed at the maintenance level approved by the procuring activity and in accordance with the approved maintenance plan. Maintenance tasks, both corrective and preventive, shall be generated by the following methods as identified in the final approved maintainability verification, demonstration, and evaluation plan.

4.3.1.1 Actual operation of the item in the specified test, operational, and maintenance environment. This method is preferred, provided that assurance can be given that sufficient number of maintenance tasks will occur during the test period to satisfy the minimum sample requirements for the test method employed (see Appendix B).

4.3.1.2 Fault simulation by introduction of faulty parts, deliberate misalignment, open leads, shorted parts, etc. A maintenance task sampling plan shall be prepared by the contractor in accordance with the procedure described in Appendix A or as directed by the procuring activity for approval by the latter. The actual task selection, by the test team, shall not be accomplished until immediately prior to the demonstration.

4.3.1.3 "Special" maintenance tasks which require unique skills, equipment, test methods, etc., will be selected by the procuring activity. The method of demonstrating these tasks will be specified by the procuring activity.

4.3.2 Turnaround Tasks. Tasks comprising turnaround shall be demonstrated. These tasks shall be determined from the planned operational use of the item.

4.3.3 Test Method. Statistical test methods and criteria for deciding whether specified maintainability requirements have been met are described in Appendix B. Guidance on selection and application of the test methods is included with each. Selection of the test method shall be from Appendix B, subject to procuring activity approval or as otherwise specified.

4.4 Administration. The following shall apply in the administration of the verification, demonstration and evaluation of the maintainability of the item.

4.4.1 Test Team Responsibility. The procuring activity/contractor verification, demonstration, and evaluation team(s) for each of the three (3) applicable phases shall be empowered to make decisions for their respective organizations. Each member of the team may have advisors from his organization who are knowledgeable in the various aspects of the demonstration and the requirements of the verification/demonstration/evaluation plan. The responsibilities of the team are in accordance with the contractors approved maintainability verification/demonstration/evaluation plan and shall include, but are not limited to the following:

4.4.1.1 To maintain surveillance over maintenance and inspection operations. Any apparent discrepancies in maintenance task accomplishment and documentation observed by any member of the team will be brought to the attention of the remaining test team members within one working day of the occurrence for appropriate action.

4.4.1.2 To evaluate and validate maintenance and operational data to determine applicable manhours, flying hours, operating time, maintenance time, downtime, item status, etc.

4.4.1.3 To assure that the demonstration item selected has been adequately prepared in accordance with applicable technical manuals and that no maintenance has been deferred that will compromise the successful completion of the next scheduled operation or mission prior to being placed in an operational ready status.

4.4.1.4 To decide if resulting failures, maintenance time, elapsed downtime, maintenance manhours, etc., should be chargeable in cases where operator or maintenance crew errors have been committed.

4.4.1.5 To rule on questions of whether or not the verification, demonstration, and evaluation plan has been adhered to.

4.4.1.6 To rule on controversial points which may arise that are not specifically covered by applicable specifications or other pertinent documentation. To determine those matters which require contractual interpretation or resolution by the appropriate government and contractor organizations. For these matters, the test team majority and minority statements shall be submitted to the procuring activity contracting officer for resolution.

4.4.1.7 To prepare and submit demonstration status reports to the procuring activity and the contractor.

4.4.1.8 To analyze data and determine the extent of achievement of specified maintainability requirements.

4.4.1.9 To prepare and submit final results of each of the phases to the procuring activity and the contractor within the time period indicated in the approved test plan.

4.4.1.10 To assure that the following conditions have been fulfilled prior to the start of Phase II and Phase III and that a letter has been sent to the procuring activity which so attests.

4.4.1.10.1 Each test item complies with the established configuration or that all deviations reported have been accepted by the procuring

activity. It shall be the responsibility of the contractor to report all deviations from the approved configuration.

4.4.1.10.2 All required technical manuals have been updated as necessary.

4.4.1.10.3 The support resources are available in the type and quantity specified in the verification, demonstration, and evaluation plan.

4.4.1.10.4 All operator or maintenance crew personnel are properly trained and meet established skill level requirements.

4.4.1.10.5 All records of approved changes in personnel requirements, operating and maintenance manuals, data handling procedures, and analysis techniques have been incorporated in the final revision of the verification, demonstration, and evaluation plan.

4.4.2 Test Director. An individual, designated by the procuring activity, as test director, shall decide in all cases of deadlock between the members of the team (subject to contract negotiations where contractual obligations are in question).

4.4.3 Instrumentation Failures. Any failures of test instrumentation used to instrument the demonstration item for test purposes or failures induced by such test instrumentation installation or operation, and all associated maintenance, shall not be chargeable.

4.4.4 Maintenance Due To Secondary Failures. If any secondary failures result from a chargeable primary failure, the total resultant maintenance time to restore the items shall be chargeable as a single maintenance task, except when the secondary failure results from the method used to simulate a fault rather than from the fault itself. If the reason for the secondary failure is removed (corrected), the time charge for the secondary failure shall be deleted.

4.4.5 Inadequate Technical Manuals Or Support Equipment. If, in the accomplishment of a maintenance task, a technician finds the applicable technical manuals or support equipment to be inadequate, these instances shall be brought to the attention of the test team and, if the inadequacy is verified, this portion of the demonstration shall be terminated and times measured shall not be chargeable. Action shall be taken to correct the inadequacies of the technical manuals or support equipment, after which the same maintenance task shall be repeated.

4.4.6 Cautions. If an item is damaged or maintenance errors induced by item design complexity, by poor design practice, or by following improper procedures that allow improper maintenance (e.g., interchangeability of connectors) without proper caution in the technical manuals, the failure and resultant maintenance times shall be chargeable. Action shall be taken to correct the improper procedures or deficiencies and the corrective action verified. When this action is completed, the maintenance time saved shall be deleted.

4.4.7 Personnel Number and Skill. Each task shall be performed by the prescribed number of personnel with the prescribed specialty codes and skills. If personnel are required on an intermittent or sequenced basis, the manhours assessed against the maintenance task will include the required standby time only if the standby time is of a type or duration which prevents standby personnel from performing other productive tasks.

4.4.8 Cannibalization. The maintenance associated with the removal or reinstallation of the item or support equipment assemblies and/or components for cannibalization purposes shall not be chargeable unless the deficiency can be directly related to lack of contractor recommendations for proper level of support spares or expendables. If the contractor takes action to correct the deficiency, the time charged shall be deleted.

4.4.9 Availability. An item shall be considered in an operationally available or operationally ready status (for aircraft) if it is capable of performing in accordance with the item's specification or capable of performing the next scheduled assigned mission.

4.4.10 Maintenance Inspection. The look portion of any inspection such as pre-flight, post-flight, or phase of a phased inspection shall be considered a separate preventive maintenance task. Each fix of the fix portion of an inspection shall be considered a separate corrective maintenance task.

4.5 GFE/GFAE Items. For Government Furnished Equipment (GFE) and Government Furnished Aeronautical Equipment (GFAE) items, the contractor is responsible for determining the GFE/GFAE maintainability characteristics and values required for his Configuration Item (CI), and for assuring that the GFE/GFAE maintainability characteristics and values are not degraded unless compensated for by the demonstrated characteristics and values for other Contractor Furnished Equipment (CFE) or GFE/GFAE. The government will furnish data on known or estimated values of GFE/GFAE reliability and maintainability which shall be used, as applicable, in the

contractor's judgment. The contractor is responsible for estimating and demonstrating the maintainability requirements of the entire CI.

4.6 Data Collection. The data collection system used in Phase I and data elements collected shall meet the needs of the objectives of Phase I. In addition, the data system and data elements shall be compatible with the data system used and data elements collected in Phases II and III. During Phase II and Phase III, the test team shall establish and operate a data center. All data recorded by the test team shall be made available to the contractor through the data center. The test team shall utilize the data system specified by the procuring activity, to record all mission debriefing, failure and maintenance data. The contractor shall describe maintenance tasks in a manner which will allow proper identification within the services maintenance data collection system that a particular task has occurred. For example, when using the System Effectiveness Data System (SEDS), the maintenance task description must contain a Work Unit Code, How Malfunctioned, and Action Taken Code which uniquely identify that task. Supplementary data collection may be incorporated if approved by the procuring activity. For those items which the contractor has depot level repair responsibilities, he shall be responsible for preparation, accuracy, and feedback of the depot level verification, demonstration, evaluation maintenance data for all depot repairables generated. All depot level data elements collected shall be compatible with the data elements collected and recorded at the organizational and intermediate maintenance levels. All direct maintenance downtime or manhours, as applicable, which is not specifically determined to be nonchargeable shall be included in the demonstration data and in the calculated quantitative value which determines compliance or noncompliance. Maintenance which might not be chargeable could result from such causes as:

4.6.1 Maintenance and operational errors not chargeable to technical manuals, contractor furnished training or faulty design.

4.6.2 Miscellaneous tasks such as keeping of records, taxiing and towing of aircraft to or from an area other than the assigned work center area.

4.6.3 Repair of accident damage.

4.6.4 Documented delay downtime (supply or administrative) which is clearly outside the responsibility of the contractor.

4.6.5 Modification tasks.

4.6.6 Maintenance of test instrumentation exclusive of normal configuration.

4.6.7 Maintenance time accountable to test instrumentation installations (other than normal configuration) accrued during maintenance task performance.

4.7 Maintainability Parameter Calculations. All data acceptable to the team and generated by the demonstration shall be used in calculating the M parameters. The following are typical maintainability parameters which may be stated in the specification: Mean-Time-To-Repair (MTTR), manhour rate, critical maintenance time or manhours, critical percentile, and chargeable maintenance downtime (a parameter for demonstration of availability). Appendix B provides methods for calculating these values and the criteria for determining whether the requirements have been achieved. Other methods of calculation tailored to a specific procurement may be provided/approved by the procuring activity.

4.8 Maintainability Verification/Demonstration/Evaluation Reports. A final report shall be submitted by the test team, after each phase, to the procuring activity in accordance with the schedule incorporated in the verification/demonstration/evaluation plan and the data requirements per Contractor Data Requirements List (DD Form 1423). The procuring activity may require interim reports where additional detail or extended test durations may be involved. The final report shall include, as a minimum, the following:

4.8.1 Summary of data collected and location of data file.

4.8.2 Factors which influence the data.

4.8.3 Analysis of the data.

4.8.4 Results of the phase and certification that the specified objectives and requirements have or have not been met.

4.8.5 Assessment of the integrated logistic support factors, such as technical manuals, personnel, tools and test equipments, support equipment, maintenance concept and provisioning for their effect on quantitative and qualitative demonstrated maintainability parameters.

4.8.6 Deficiencies.

4.8.7 Recommendations:

4.8.7.1 to correct deficiencies and

4.8.7.2 for suggested improvements.

4.8.8 Results of retest (if applicable). To be submitted as a supplement to the final report.

5. ORDERING DATA

The selected data requirements in support of this standard shall be reflected in the Contractor Data Requirements List (DD Form 1423) attached to the Request for Proposal, Invitation for Bid, or the Contract, as appropriate. The following information will be included in the applicable contractual documents:

a. Phases applicable to the procurement (see 1.2).

b. Dates for submission of the test plan and test procedures for each phase (see 4.1, 4.2).

c. Type of personnel (government or contractor who will operate and maintain the item for maintainability demonstration) (see 4.1.2.2).

d. Dates for submission of the final, interim and supplemental (if required) reports for each phase (see 4.8).

e. Data collection system (4.6).

f. Specification Requirements and Test Method (see Appendix B; B.10.2 for major characteristics for the test method specified).

CUSTODIANS

Army - EL
Navy - AS
Air Force - 17

REVIEW ACTIVITIES

Army - EL, MI, SC, TE
Navy - EC
Air Force - 10, 11, 13, 15, 22, 26

USER ACTIVITIES

Army -
Navy -
Air Force - 19, 71, 80

PREPARING ACTIVITY

Air Force - 17
Project MISC-0855

APPENDIX A

MAINTENANCE TASK SAMPLING FOR USE WITH FAILURE SIMULATION

A.10 Scope.

A.10.1 Purpose. This appendix outlines a procedure for the selection of a sample of corrective maintenance tasks for maintainability demonstration when the tasks result from failure simulation.

A.10.2 Application. The procedure described herein is applicable only when failure simulation is to be used to generate maintenance tasks. The procedure is applicable to the equipment level and it is assumed that system level maintainability requirements have been allocated to the equipment level for demonstration. The mean estimates for equipment may be employed to determine achievement of system maintainability requirements. If sampling of preventive maintenance tasks or servicing is permitted, a procedure and tables similar to that illustrated in this appendix for corrective maintenance must be developed for each type of task (i.e., preventive maintenance, servicing).

A.10.3 Sample Stratification. The major objectives of stratification in this standard are to: (a) allow for the selection of maintenance tasks in such a manner that the selection simulates the failure frequency of the test unit in actual operation, (units with low MTBF's will be selected more frequently than units with higher MTBF's), (b) insure that a proportionately representative sample of task types/times are selected. Proportional stratified sampling may be used for selection of maintenance tasks to be demonstrated using the fixed sample size test methods described in Appendix B. Sequential test method shall employ simple random sampling.

A.10.4 Stratification Procedure. The following example illustrates the procedure for tasks which would be classified as corrective maintenance. Preventive maintenance or servicing tasks should not be combined with corrective maintenance tasks for the purpose of task stratification. For system level demonstration of maintainability requirements, the procedure should be applied to each contract end item equipment and through appropriate techniques, the achievement of system maintainability requirements may be demonstrated. Maintenance tasks may be performed concurrently or serially provided that provision has been made to record the expended maintenance time for each maintenance task. The requirement to be demonstrated shall determine the manner in which the data shall be analyzed. The following, Table I, illustrates the application of this procedure to a radar equipment consisting of: Antenna, Receiver/Transmitter, Frequency Tracker, Radar Set Control, and Drift Angle Indicator:

Supersedes page 19 of 27 March 1973

a. Column 1 - Identify the major units which comprise the equipment.

b. Column 2 - Subdivide each unit to the functional level at which maintenance for the demonstration is to be performed in accordance with the approved maintenance plan. This level may be an assembly, module, printed circuit card or piece part.

c. Columns 3 & 4 - For each functional level of maintenance identified in Column 2, identify in Column 3 the type of maintenance task or tasks to be performed and in Column 4 the estimated mean maintenance time for the task. The maintenance task time shall include the time to perform each element of maintenance time as defined in MIL-STD-721B. The maintenance tasks and estimated maintenance time would be derived from a maintenance engineering analysis, a maintainability prediction effort, or from historical data. The same maintenance task, such as "remove and replace" of a module may result from different faults within the module. Column 3 would identify the maintenance task and not the fault or failure which results in the occurrence of the task.

d. Column 5 - Determine the failure rate ($F/10^6$ hr.) for each module, printed circuit card, etc., for which the maintenance task was identified in Column 3. The failure rates used shall be the latest available from the associated reliability program. If there is no reliability program, the failure rates may be selected or extrapolated from sources approved by the procuring activity.

e. Column 6 - Determine the quantity of items in each major unit associated with each task in Column 3.

f. Column 7 - Determine the duty cycle for each item associated with each task in Column 3 (e.g., operating time of a receiver to the operating time of the radar; engine operating hours to aircraft flight hours).

g. Column 8 - Group together the maintenance tasks identified in Column 3 which have both:

(1) Similar maintenance actions. NOTE: A maintenance action is an element of a maintenance task. Although the estimated maintenance time for different maintenance tasks may be similar, the actions may be different, that is, one task may involve significant diagnostics and another involve minimum diagnostics but significant access time.

(2) Similar estimated maintenance times. The maintenance times in each group shall be within a range that shall not exceed the smallest value in the group by more than 50 percent.

Task grouping shall be limited to within major units identified in Column 1.

h. Column 9 - Determine the total failure rate for each task grouping identified in Column 8. The total failure rate is equal to the sum of the products of Columns 5 x 6 x 7 for all tasks within the group.

i. Column 10 - Determine the relative frequency of occurrence for each task grouping by dividing the sum of the total failure rate (sum of Column 9) into the individual total failure rate for each group.

j. Column 11 - Fixed Sample - A sample of maintenance tasks equal to at least four times the sample size specified for the selected test method (Appendix B) or as specified by the procuring activity, shall be allocated among the task groups in accordance with the relative frequency of occurrence of the task group. Example: Assume the test method to be employed requires that a sample of 50 maintenance tasks be demonstrated, a sample of 200 tasks (4 x 50) shall be allocated among the task groups as follows:

Group 1 - .177 x 200 = 35 tasks;

Group 2 - .178 x 200 = 36 tasks;

Group 3 - .016 x 200 = 3 tasks;

Group 7 - .013 x 200 = 3 tasks,

This allocation is shown in Column 11. The maintenance tasks allocated to each group shall be randomly selected and identified from the population of maintenance tasks applicable to that group. The total number of maintenance tasks which must be identified for the equipment must be equal to or greater than four times the demonstration sample size (i.e., greater than 4 x 50 = 200 for this example) in order that the number of tasks identified with each group is sufficient such that the allocation of tasks to each group (i.e., 35 tasks for Group 1; 36 tasks for Group 2, etc.) may be randomly selected from the population of tasks identified as applicable to that group. The maintenance tasks which have been randomly selected shall not be returned to the sample pool. When a task group consists of more than one module or assembly, etc., such as group 2 of Table I, the maintenance tasks assigned to the group (Column 11, 36 tasks for this example) shall be allocated to the modules, assemblies, etc., within the group in accordance with the relative frequency of occurrence of maintenance for each module, etc., within the group. The procedure would be the same as that used to determine the relative frequency of occurrence of the task groups (Column 10) but would be applied to the

Supersedes page 21 of 27 March 1973

modules, etc., within the group. This is illustrated below with the allocation shown included in Table I, Column 11, Group 2.

Group 2	Total Failure Rate	Relative Freq. of Occ.	Demonstration Population Allocation
A-IF-A	23	.217	7.8≈8 (.217 x 36 = 7.8)
B-IF-B	21	.198	7.4≈7
C-Amplifier	21	.198	7.1≈7
D-Modulator	18	.170	6.0≈6
E-Power Supply	23	.217	7.8≈8
	106	1.000	36

k. Column 12 - The maintenance tasks to be demonstrated (50 tasks for this example) shall be allocated among the task groups in accordance with the relative frequency of occurrence of maintenance for the group.

Example:

Group 1: .177 x 50 = 8.85≈9 tasks;

Group 2: .178 x 50 = 8.90≈9 tasks;

Group 3: .016 x 50 = .80≈1 task,

Group 7: .013 x 50 = .65≈1 task

If a task group consists of more than one module, assembly, etc., such as group 2, Table I, the maintenance tasks to be demonstrated from the group (column 12, 9 tasks for this example) shall be allocated to the modules, assemblies, etc., within the group in accordance with the relative frequency of occurrence of maintenance for each module, etc., within the group. This is illustrated below with the sample allocation shown included in Table I, column 12.

Group 2	Relative Freq. of Occurrence	Demonstration Sample Size
IF-A	.217	1.95≈2 (.217 x 9 = 1.95)
IF-B	.198	1.78≈2
Amplifier	.198	1.78≈2
Modulator	.170	1.53≈1
Power Supply	.217	1.95≈2
		9 total

Supersedes page 22 of 27 March 1973

The maintenance task to be demonstrated shall be randomly selected from the maintenance tasks allocated to the group or modules, assemblies, etc., within the group or modules, assemblies, etc., within the group (column 11). The maintenance task to be demonstrated shall not be returned to the sample pool and shall be demonstrated once only unless otherwise permitted by the procuring activity.

1. Column 13 - Variable Sample/Sequential Test - When variable sample size, sequential test methods are employed a simple random sampling of the total population of maintenance tasks using a random number table based on a uniform distribution from 0 to 1 shall be used. Using Table I columns 1 through 10 determine from the relative frequency of occurrence (column 10), the cumulative range of frequency of occurrence for each task group. A maintanance task is selected from that group whose cumulative range of frequency of occurrence includes the number selected from the random number table. The number selected from the random number table shall be "returned" to the table before selecting a second number. The "specimen" task demonstrated shall be returned to the sample pool.

A.10.5 Failure Mode Selection. A failure mode and effect analysis (FMEA), applied to the functional level at which maintenance is to be performed, shall be used to determine the failure modes or faults (open, short, etc.), which will result in the occurrence of the maintenance task of interest. To avoid duplication of effort, the FMEA shall utilize inputs from and be coordinated with the reliability program efforts. The relative frequency of occurrence of the failure mode will determine the fault to be simulated. This procedure is illustrated in Table II.

a. Column 1 - Identify the maintenance task of interest.

b. Column 2 - Determine the failure modes which will result in the maintenance task of interest.

c. Column 3 - Determine the effect of each failure mode identified in column 2.

d. Column 4 - Determine the relative frequency of occurrence of each failure mode.

e. Column 5 - Simple Random Sampling - Determine the cumulative range of frequency of occurrence for each failure mode. Using a random number table a number is selected and the failure mode to be induced is that whose cumulative range of frequency of occurrence includes the number selected. The number selected from the random number table shall be "returned" to the table before selecting a second number. The specimen demonstrated shall be returned to the sample pool.

TABLE I - STRATIFICATION PROCEDURE

Equipment - Radar XYZ

(1) Major Units	(2) Functional Level of Maintenance	(3) Maintenance Task	(4) Est. Mean Maint. Time (hrs)	(5) Failure Rate F/10^6 hrs.	(6) Quantity of Items	(7) Duty Cycle	(8) Task Grouping	(9) Total Failure Rate	(10) Relative Freq. of Occurrence	FIXED SAMPLE (11) Demon. Population Allocation	FIXED SAMPLE (12) Demon. Sample Size	VARIABLE SAMPLE (13) Cumulative Range
Antenna	Antenna	R/R(A)	1.0	105	1	1.0	Group 1 Task A	105	0.177	35	9	0 - .1769
Receiver/ Transmitter	IF-A	R/R(A)	0.3	23	1	1.0	Group 2 Tasks A, B,C,D,E	106	0.178	A-8	A-2	
										B-7 36	B-2 9	.1770 - .3549
	IF-B	R/R(B)	0.3	21	1	1.0				C-7	C-2	
	Amplifier	R/R(C)	0.4	21	1	1.0				D-6	D-1	
	Modulator	R/R(D)	0.4	18	1	1.0				E-8	E-2	
	Power Supply	R/R(E)	0.4	23	1	1.0						
	Transmitter	R/R(F)	0.5	10	1	1.0	Group 3 Task F	10	0.016	3	1	.3550 - .3709
Freq. Tracker	Freq. Tracker	R/R(A)	0.6	400	1	.7	Group 4 Task A	280	0.472	94	23	.3710 - .8429
		Replace Crystals(B)	0.5	20	4	.7	Group 5 Task B	56	0.094	19	5	.8430 - .9369
Radar Set Control	Radar Set Control	R/R(A)	0.5	35	1	.8	Group 6 Task A	28	0.047	10	2	.9370 - .9839
Drift Angle Indicator	Drift Angle Indicator	R/R(A)	0.5	10	1	.8	Group 7 Task A	8	0.013	3	1	.9840 - 1.00
								593	1.00	200	50	

NOTE 1: R/R = remove/replace (includes time to perform each element of maintenance time as defined in MIL-STD-721).

NOTE 2: This table is for illustration only. It is not intended to represent a complete radar nor should the entries be considered as real data.

NOTE 3: Delete column 11 and column 12 for sequential test methods.

TABLE II

FAILURE MODE SELECTION

1 Maintenance Task	2 Failure Mode	3 Effect	4 Relative Frequency of Occurrence (Percent)	5 Cumulative Range (Percent)
Receiver Remove/ Replace	1. Component out of tolerance	1. Noise	.20	0 - .199
	2. Component shorted/open	2. Receiver Inoperative	.35	.200 - .549
	3. Tuning failure	3. Cannot change frequency	.45	.550 - 1.00

NOTE: This table is for illustration only and does not reflect real failure modes, etc.

APPENDIX B

TEST METHODS AND DATA ANALYSIS

B.10 Scope.

B.10.1 Purpose - This appendix contains test methods and criteria for demonstrating the achievement of specified quantitative maintainability requirements: Some of the test methods included are identical to test methods contained in previous versions of this Standard. Table IA indicates the correspondence of the test methods included in this Standard to those included in past versions.

B.10.2 Application - The following matrix (Fig. B-1) summarizes the major characteristics of each test method as well as the quantitative requirements which must be specified for each test method. The data analysis method included with each test method provides the decision criteria for acceptance or rejection of the item being demonstrated.

B.10.3 Sample Size - Each of the test plans contained in this appendix includes an equation or other directions for determining a minimum sample size of maintenance tasks. Any departure from the minimum sample size requirement can affect the statistical validity of the test procedures. Some of the test plans in the appendix require a prior estimate of the variance of the distribution of interest for the calculation of sample size. Such prior estimates, subject to government approval, can be obtained from data on similar equipment provided similarities in maintainability design, skill levels of maintenance personnel, test equipment, manuals and the maintenance environment are considered in the estimation process. Equations for predicting the variance when prior estimates are not available are presented in DDC document AD-869396, Maintainability Prediction and Demonstration Techniques, Vol. II, cited in para. B.10.6, which can be used, provided the information needed for the prediction is available. The 85th - 95th upper confidence bound on the predicted or estimated variance shall be used to insure preservation of the desired risk values. Average observed values of the variance have ranged from $\sigma^2 = .5$ to $\sigma^2 = 1.3$.

B.10.4 Task Selection - Selection of tasks to be sampled when employing fault simulation will be made in accordance with Appendix A of this standard. The Procuring Activity shall have the option of surveillance over and/or participating in the random selection of tasks comprising the demonstration population (Column 11 of Table I) down to and including the specific faults to be simulated. This shall occur at a specific conference at a time established by the contractor, consistent with the Maintainability Program Plan schedule. In the event that tasks so chosen can result in events detrimental to safety of personnel or property, appropriate redesign action must take place; in the event that secondary failures result, they will be documented and their impact on item maintainability assessed. A report of such findings shall be made to the procuring activity. Care must be exercised in selecting and sampling tasks to insure that a true simple random sample is obtained when sequential tests are employed. Departures from simple random sampling, such as proportionate stratified sampling, can effect the validity of the test procedures presented herein, however, this effect is considered minimal for the sample sizes required by the test procedures which are not sequential tests. Simple random sampling shall be used for sequential tests.

Supersedes page 26 of 27 March 1973

B.10.5 Test Selection - In general, the test index to be demonstrated is the primary consideration in selecting a test procedure. Considerable savings in sample size can be obtained by use of sequential test procedures in preference to fixed sample tests. As a general rule, however, the sequential test should be used only when prior knowledge (e.g., from the prediction) indicates that the equipment may be much better (or worse) than the specified values.

B.10.5.1 A cross-reference of the test methods in MIL-STD-471A to those which were numbered differently in the original issues, MIL-STD-471 (and Notice 1) are listed in Table IA.

TABLE IA, TEST METHOD CROSS-REFERENCE LIST

MIL-STD-471A		MIL-STD-471
Test Method 8	→	Test Method 1
Test Method 9	→	Test Method 2
Test Method 4	→	Test Method 3
Test Method 10	→	Test Method 4
Test Method 11	→	Test Method 6

Test Method	Test Index	Assumptions	Sample Size	Sample Selection	Spec. Requirement
1-A	Mean	Log Normal Dist. Prior Knowledge of Variance	See Test Method	Natural Occurring Failures or Appendix A	H_o, H_1, α, β (1)
1-B		No Distribution Assumption, Prior Knowledge of Variance	"	"	"
2	Critical Percentile	Log Normal Dist. Prior Knowledge of Variance	"	"	"
3	Critical Maint. Time or Manhours	None	"	"	"
4	Median	A Specific Var. Log Normal	20	"	ERT
5	Chargeable Maint. Down-time/Flight (2)	None	See Test Method	Natural Occurring Failures	ORR or A $\frac{NCMDT}{NOF}$, $\frac{DDT}{NOF}$, α, β
6	Manhour Rate (3)	None	"	"	Manhour Rate Δ MR
7	Manhour Rate (4)	None	"	Natural Occurring Failures or Appendix A	μ_R, α

(1) See B.10.7 for definitions of α, β, H_o, H_1
(2) Test Method 5 is an indirect method for demonstrating operational ready rate (ORR) or Availability (A).
(3) Test Method 6 is intended for use with aeronautical systems and subsystems.
(4) Test Method 7 is intended for use with ground electronic systems where it may be necessary to simulate faults.

Fig. B-1 TEST METHOD MATRIX

Supersedes page 27 of 27 March 1973

Test Method	Test Index	Assumptions	Sample Size	Sample Selection	Spec Requirement
8	Mean and Percentile ------------------- Dual Percentile	Lognormal --------- None	See Test Method	Natural Occurring or Simple Random Sampling	Mean, M_{max} ---------- Dual Percentile
9	Mean (Corrective Task Time, Prev. Maint. Time, Down-time) ------------------ M_{max} (90 or 95 percentile)	None	30 minimum	Natural Occurring or Appendix A	μ_c, μ_{pm}, $\mu_{p/c}$ M_{max_c}
10	Median (Correct Task Time, Prev. Maint. Task Time) M_{max} (95 percentile) Corrective Maint. Task Time, Preventive Maint. Task Time	None	50 minimum	Natural Occurring or Appendix A	$\tilde{M}_{ct}$, $\tilde{M}_{dt}$, M_{max_c}, $M_{max_{pm}}$
11	Mean (preventive maint. task time) M_{max} (preventive maintenance task time, at any percentile)	None	All possible tasks	All	μ_{pm} $M_{max_{pm}}$

Fig. B-1- TEST METHOD MATRIX (CONTINUED)

The justification for use of the log-normal assumption for corrective maintenance times is based on extensive analysis of field data which have shown that the log-normal distribution provides a good fit to the data. However, in those cases where it is suspected that the log-normal assumption does not hold (e.g., equipments with a high degree of built-in diagnostics) then a distribution-free method should be employed to insure preservation of specified risks.

B.10.6 References - Details and additional references for the test plans (1, 2, 3) presented in this appendix can be found in RADC Technical Report 69-356 (AD 869 396), Volume II, entitled: "Maintainability Prediction and Demonstration Techniques." Copies of this document may be obtained from the Defense Documentation Center, Cameron Station, Alexandria, VA 22314.

B.10.7 List of Symbols - The following symbols and notations are common the test methods 1 - 3 contained in this appendix:

X = the random variable which denotes the maintenance characteristics of interest (e.g., X can denote corrective maintenance time, preventive maintenance time, fault location time, manhours per maintenance task, etc.).

X_i = the ith observation or value of the random variable X.

n = the sample size

$\overline{X}$ = the sample mean (i.e., $\overline{X} = \frac{1}{n}\sum_{i=1}^{n} (Xi)$

$\sigma^2 = E\left[(\ln X-\theta)^2\right]$ = the true variance of lnX

$\mu = E(X)$ = the true mean of X.

$d^2 = Var(X) = E\left[(X-\mu)^2\right]$ = the true variance of X.

$\hat{d}^2$ = the sample variance of X (i.e., $\hat{d}^2 = \frac{1}{n-1}\sum_{i=1}^{n} (Xi-\overline{X}^2)) = \frac{1}{n-1}\left(\sum_{i=1}^{n} Xi^2 - n\overline{X}^2\right)$

$\tilde{d}^2$ = the prior estimate of the variance of the maintenance time

X_p = the (1-p)th percentile of X (i.e., X.05 = 95th percentile of X).

$\tilde{M} = X_{.50}$ = the median of X.

$Y = \ln X$ = the natural logarithm of X.

$\overline{Y}$ = the sample mean of Y

$\theta = E(\ln X)$ = the true mean of ln X.

$\tilde{\sigma}^2$ = the prior estimate of the variance of the logarithm of maintenance times

s^2 = the sample variance of ln X.

Z_p = the standardized normal deviate exceeded with probability p (i.e.,

$$\int_{Z_p}^{\infty} \frac{1}{\sqrt{2\pi}} e^{\frac{-z^2}{2}} d_z = p$$

Z_α $Z_{(1-\beta)}$ = standardized normal deviate exceeded with probabilities α and $(1-\beta)$ respectively.

α = the producer's risk, the probability that the equipment will be rejected when it has a true value equal to the desired value (H_o).

β = the consumer's risk; the probability that the equipment will be accepted when it has a true value equal to the maximum tolerable value (H_1).

H_o = the desired value specified in the contract or specification and is expressed as a mean, critical percentile, critical maintenance time.

H_1 = the maximum tolerable value. Note: $H_o < H_1$.

When X is a log-normally distributed random variable:

$$f(x) = \frac{1}{\sigma x \sqrt{2\pi}} e^{-\frac{1}{2\sigma^2}(\ln x - \theta)^2}, \quad 0 < x < \infty$$

If Y = ln X, the probability density of Y is normal with mean θ and σ^2 variance

$$Y \sim N(\theta, \sigma^2)$$

<u>Properties of the log-normal distribution:</u>

mean = $\mu = e^{\left(\theta + \frac{\sigma^2}{2}\right)}$

variance = $d^2 = e^{(2\theta + \sigma^2)}\left(e^{\sigma^2} - 1\right)$

median = $\tilde{M} = e^{\theta}$

mode = $M = e^{(\theta - \sigma^2)}$

(1-p)th percentile = $X_p = e^{(\theta + Z_p \sigma)}$

Table of standardized normal deviates:

P	Z_p
.01	2.33
.05	1.65
.10	1.28
.15	1.04
.20	.84
.30	.52

B.10.8 List of Symbols. The following symbols are common to the test methods 4, 8 - 11 contained in this Appendix:

X_{ci} = Maintenance downtime per corrective maintenance task (of the i^{th} task).

X_{pmi} = Maintenance downtime per preventive maintenance task (of the i^{th} task).

n_c = Number of corrective maintenance tasks sampled.

n_{pm} = Number of preventive maintenance tasks sampled.

β = Consumer's risk.

ϕ = That value, corresponding to risk, which is obtained from a table of normal distribution for a one-tail test.

f_c = Number of expected corrective maintenance tasks occurring during a representative operating time (T).

f_{pm} = Number of expected preventive maintenance tasks occurring during a representative operating time (T).

T = Item representative operating time period.

D_t = Total maintenance downtime in the representative operating time (T).

$\bar{X}_c, \bar{X}_{pm}, \bar{X}_{p/c}$ = Mean downtimes of sample. (Corrective, Preventive, and combined Corrective/Preventive Maintenance Times.)

M'_{max_c} = Sample calculated maximum corrective maintenance downtime.

$\mathcal{M}c$ = Specified mean corrective maintenance time.

$\mathcal{M}pm$ = Specified mean preventive maintenance time.

Supersedes page 30 of 27 March 1973

$\mu_{p/c}$ = Specified mean maintenance time. (Taking both corrective and preventive maintenance time into account.)

M_{max} = A requirement levied in terms of a maximum value of a percentile of task times (i.e., 95% of all corrective task times must be less than 60 minutes) usually taken as the 90th or 95th percentile.

M_{max_c} = Specified M_{max} of corrective maintenance downtimes.

$M_{max_{pm}}$ = Specified M_{max} of preventive maintenance downtimes.

θ_c = $E(\ln X_c)$ = Expected value of the logarithms of corrective maintenance tasks.

$\text{Log } X_{ci}$, $\text{Log } X_c$ = Log to the base 10 of X_{ci}, X_c.

$\ln X_{ci}$, $\ln X_c$ = Natural logs of X_{ci}, X_c.

$\widetilde{M}_{ct}$ = Median value of corrective maintenance tasks.

$\widetilde{M}_{pm}$ = Median value of preventive maintenance tasks.

TEST METHOD 1

TEST ON THE MEAN

B.20 General - This test provides for the demonstration of maintainability when the requirement is stated in terms of both a required mean value (μ_1) and a design goal value (μ_0) (or when the requirement is stated in terms of a required mean value (μ_1) and a design goal value (μ_0) is chosen by the contractor). The test plan is subdivided into two basic procedures, identified herein as Test Plan A and Test Plan B. Test A makes use of the lognormal assumption for determining the sample size, whereas Test B does not. Both tests are fixed sample tests, (minimum sample size of 30), which employ the Central Limit Theorem and the asymptotic normality of the sample mean for their development.

B.20.1 Assumptions - Test A - Maintenance times can be adequately described by a lognormal distribution. The variance, σ^2, of the logarithms of the maintenance times is known from prior information or reasonably precise estimates can be obtained. Test B - No specific assumption concerning the distribution of maintenance times are necessary. The variance d^2 of the maintenance times is known from prior information or reasonably precise estimates can be obtained.

B.20.2 Hypotheses - H_0: Mean $= \mu_0$ (1-1)

H_1: Mean $= \mu_1$, $(\mu_1 > \mu_0)$ (1-2)

Illustration: H_0: $\mu_0 = 30$ min.

H_1: $\mu_1 = 45$ min.

B.20.3 Sample Size - For a test with producer's risk α and consumer's risk β, the sample size for Test A is given by:

$$n = \frac{(Z_\alpha \mu_0 + Z_\beta \mu_1)^2}{(\mu_1 - \mu_0)^2} \left(e^{\tilde{\sigma}^2} - 1\right) \tag{1-3}$$

where $\tilde{\sigma}^2$ is a prior estimate of the variance of the logarithms of maintenance times. The sample size for Test B is given by:

$$n = \left(\frac{Z_\alpha + Z_\beta}{\frac{\mu_1 - \mu_0}{\tilde{d}}} \right)^2 \tag{1-4}$$

where $\tilde{d}^2$ is a prior estimate of the variance of the maintenance times. Z_α and Z_β are standardized normal deviates.

B.20.4 Decision Procedure. Obtain a random sample of n maintenance times, $X_1, X_2, \ldots, X_n$, and compute the sample mean,

$$\overline{X} = \frac{1}{n} \sum_{i=1}^{n} X_i \tag{1-5}$$

and the sample variance

$$\hat{d}^2 = \frac{1}{n-1}\left(\sum_{i=1}^{n} X_i^2 - n\bar{X}^2\right) \qquad (1\text{-}6)$$

<u>Test A</u>: Accept if $\bar{X} \leq \mu_0 + Z_\alpha \frac{\hat{d}}{\sqrt{n}}$ (1-7)

<u>Test B</u>: Accept if $\bar{X} \leq \mu_0 + Z_\alpha \frac{\hat{d}}{\sqrt{n}}$ (1-8)

Reject otherwise.

B.20.5 <u>Discussion</u> - By the central limit theorem, the sample mean $\bar{X}$ is approximately normal for large n with mean E(X) and variance Var $(\bar{X})$. In Test A under the log-normal assumption Var $\bar{X} = \frac{d^2}{n}$ where $d^2 = e^{(2\theta+\tilde{\sigma}^2)}(e^{\tilde{\sigma}^2}-1) = \mu^2(e^{\tilde{\sigma}^2}-1)$ thus the sample size n can be computed using a prior estimate of $\tilde{\sigma}^2$. In Test B, a prior estimate of d^2 is assumed to be available to calculate the sample size. A critical value C is chosen such that $\mu_0 + Z_\alpha\sqrt{\text{Var }\bar{X}} = C = \mu_1 - Z_\beta\sqrt{\text{Var }\bar{X}}$. If $\mu = \mu_0$. Then $P(\bar{X}>C) = \alpha$ and if $\mu = \mu_1$, then $P(\bar{X} \leq C) = \beta$.

B.20.6 <u>Example</u> - It is desired to test the hypothesis that the mean corrective maintenance time is equal to 30 minutes against the alternate hypothesis that the mean is 45 minutes $\alpha=\beta=.05$.

Then $H_0: \mu_0$ = 30 minutes.

$H_1: \mu_1$ = 45 minutes.

<u>Test A</u>: Under the log-normal assumption with prior estimate of $\tilde{\sigma}^2 = .6$ the sample size using equation 1-3 is: $n_c = \frac{[1.65(30) + 1.65(45)]^2}{(45-30)^2}(e^{.6}-1) = 56$

<u>Test B</u>: Under the distribution-free case with a prior estimate of $\tilde{d}^2$ = 900, (or d = 30), the sample size using equation 1-4 is:

$$n_c = \left[\frac{3.29}{\left(\frac{45-30}{30}\right)}\right]^2 = 43$$

B.20.7 <u>O.C. Curve</u> - The OC curve for <u>Test B</u> for this example is given in Figure B-3. It gives the probability of acceptance for values of the mean maintenance time from 20 to 60 minutes. The OC curve for <u>Test A</u> for this example is given in Figure B-2. It gives the probability of acceptance for various values of the mean maintenance time. Thus, if the true value of μ is 40 minutes, then the probability that a demonstration will end in acceptance is 0.21 as seen from Fig. B-2.

Supersedes page 32 of 27 March 1973

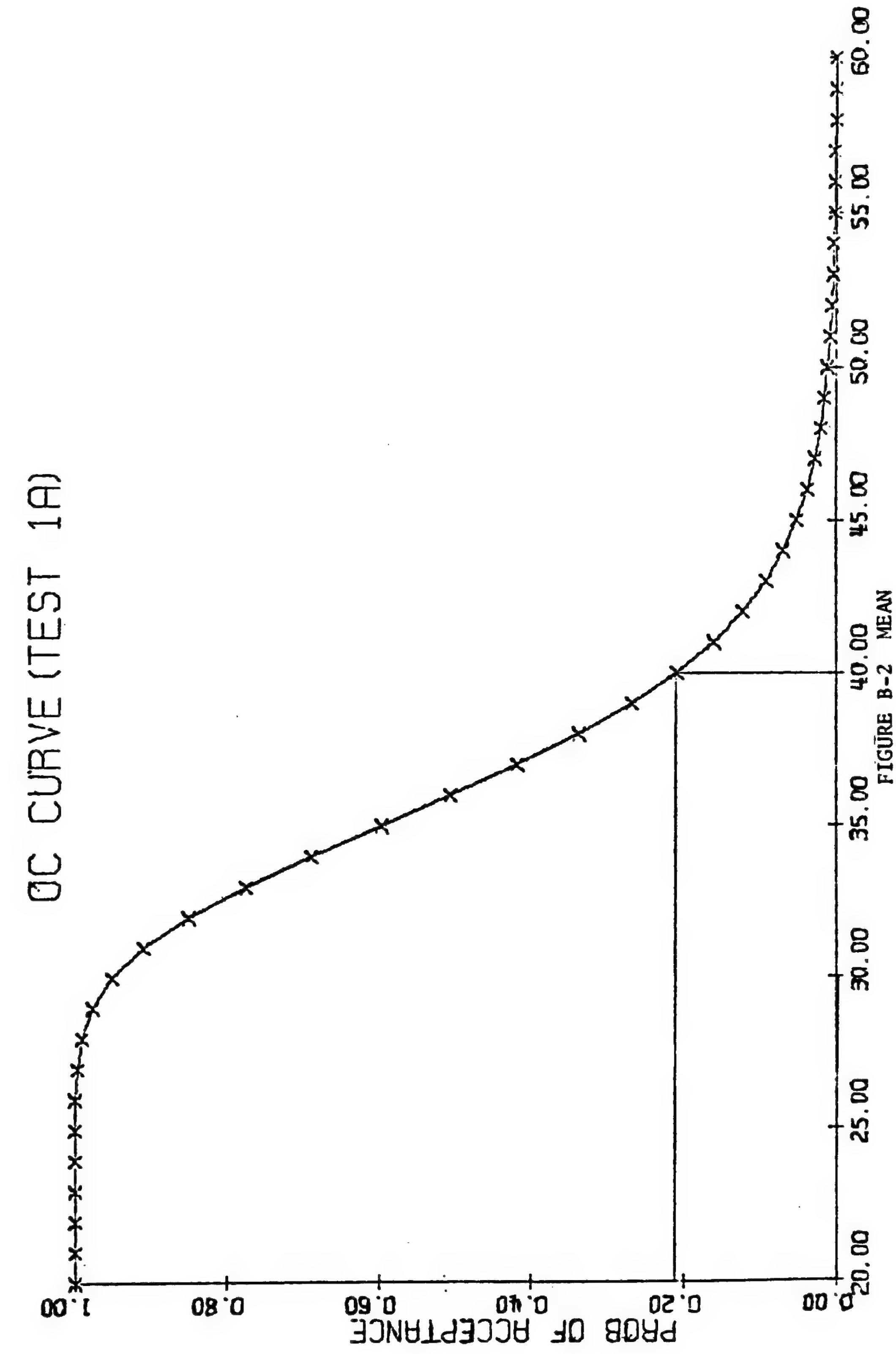

OC CURVE (TEST 1A)
PROB OF ACCEPTANCE
0.00
0.20
0.40
0.60
0.80
1.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
60.00
MEAN

FIGURE B-2

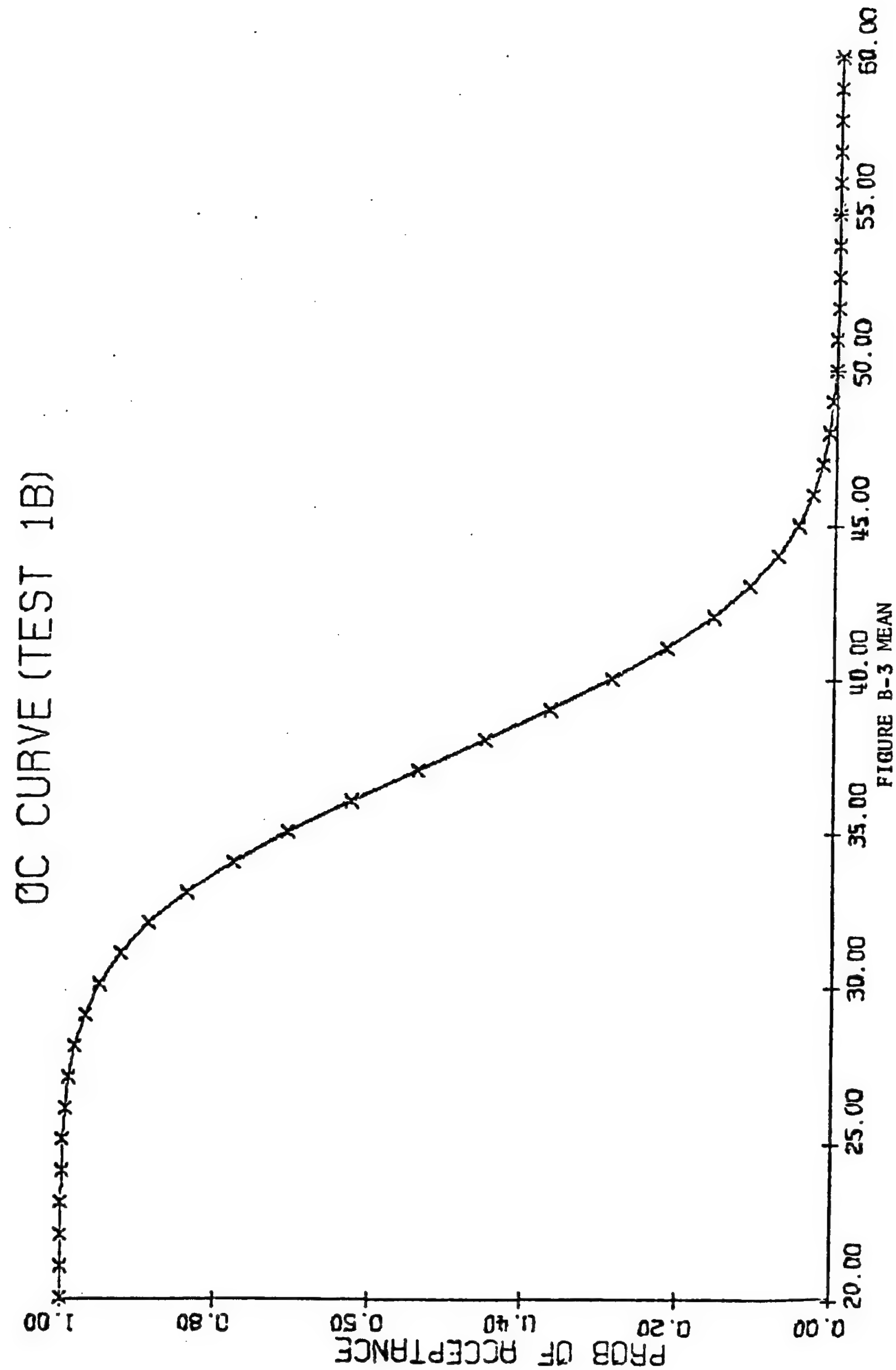

ØC CURVE (TEST 1B)
PROB OF ACCEPTANCE
0.00
0.20
0.40
0.50
0.80
1.00
MEAN
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
60.00

FIGURE B-3

TEST METHOD 2

TEST ON CRITICAL PERCENTILE

B.30 General - This test provides for the demonstration of maintainability when the requirement is stated in terms of both a required critical percentile value (T_1) and a design goal value (T_0) [or when the requirement is stated in terms of a required percentile value (T_1) and a design goal value (T_0) is chosen by the contractor]. If the critical percentile is set at 50 percent, then this test method is a test of the median. The test is a fixed sample size test. The decision criterion is based upon the asymptotic normality of the maximum likelihood estimate of the percentile value.

B.30.1 Assumption - Maintenance times can be adequately described by a log-normal distribution. The variance σ^2 of the logarithms of the maintenance times is known from prior information or reasonably precise estimates can be obtained.

B.30.2 Hypotheses - H_0: (1-p)th percentile, $X_p = T_0$ (2-1)

$$\text{or } P\left[X > T_0\right] = p$$

H_1: (1-p)th percentile, $X_p = T_1$ (2-2)

$$\text{or } P\left[X > T_1\right] = P, \ (T_1 > T_0)$$

Illustration: H_0: 95th percentile = $X_p = X_{.05}$ = 1.5 hours =

T_0: $\ln T_0 = .4055$

H_1: 95th percentile = $X_p = X_{.05}$ = 2 hours =

T_1: $\ln T_1 = .6932$

B.30.3 Sample Size - To meet specified α and β risks, the sample size to be used is given by the formula

$$n = \left(\frac{2 + Z_p^2}{2}\right) \tilde{\sigma}^2 \left(\frac{Z_\alpha + Z_\beta}{\ln T_1 - \ln T_0}\right)^2 \quad \text{(Round up to next integer)} \tag{2-3}$$

where

$\tilde{\sigma}^2$ is a prior estimate of σ^2, the true variance of the logarithms of the maintenance times.

Z_p is the standardized normal deviate corresponding to the (1 - p)th percentile.

B.30.4 Decision Procedure - Compute

$$\bar{Y} = \frac{1}{n} \sum_{i=1}^{n} \ln X_i \tag{2-4}$$

$$s^2 = \frac{1}{n-1}\left[\sum_{i=1}^{n} (\ln X_i)^2 - n\bar{y}^2\right] \tag{2-5}$$

$$X^* = \ln T_o + Z_\alpha S \left[\frac{1}{n} + \frac{Z_p^{\ 2}}{2(n-1)} \right]^{1/2} \qquad (2\text{-}6)$$

Accept if $\bar{Y} + Z_p S \leq X^*$ (2-7)

Reject otherwise.

B.30.5 Discussion - This test is based upon the fact that under the log-normal assumption, the (1-p)th percentile value is given by $X_p = e^{(\theta + Z_p \sigma)}$. Taking logarithms gives $\ln X_p = \theta + Z_p \sigma$, and using maximum likelihood estimates for the normal parameters θ and σ, the (1-p)th percentile maximum likelihood estimate is $\ln \hat{X}_p = \bar{Y} + Z_p S\sqrt{\frac{n-1}{n}}$. $\ln X_p$ is approximately normal. To meet the producer's and consumer's risk requirements, a critical value X^* is chosen for the sample estimate of the (1-p)th percentile X_p. Note $\bar{Y} = \hat{\theta}$ an estimate for θ .

B.30.6 Example - The following hypotheses are to be tested at $\alpha = \beta = .10$

H_0; 95th percentile = $X_{.05}$ = 1.5 hours = T_0; $\ln T_0$ = .4055

H_1; 95th percentile = $X_{.05}$ = 2.0 hours = T_1; $\ln T_1$ = .6932

A prior estimate of $\tilde{\sigma}^2$ is equal to 1.0 using equation 2-3.

$$n_c = \left(\frac{2 + (1.65)^2}{2} \right) (1) \frac{(2.56)^2}{(\ln 2.0 - \ln 1.5)^2}$$

or

$$n_c = 187$$

The critical value X^* is given by equation 2-5

$$X^* = \ln T_o + Z_\alpha S \left[\frac{1}{n} + \frac{Z_p^{\ 2}}{2(n-1)} \right]^{1/2}$$

$$= \ln 1.5 + 1.28S \left[\frac{1}{187} + \frac{(1.65)^2}{372} \right]^{1/2}$$

or

$$X^* = .4055 + 0.1437S$$

B.30.7 OC Curve - The OC curve for Test Method 2 for this example is given in Figure B-4. It gives the probability of acceptance for various values of the 95th percentile of the maintenance time distribution. If the true value of $X_{0.05}$ is 1.7 hours, then the probability that a demonstration will end in acceptance is 0.57 as seen from Figure B-4.

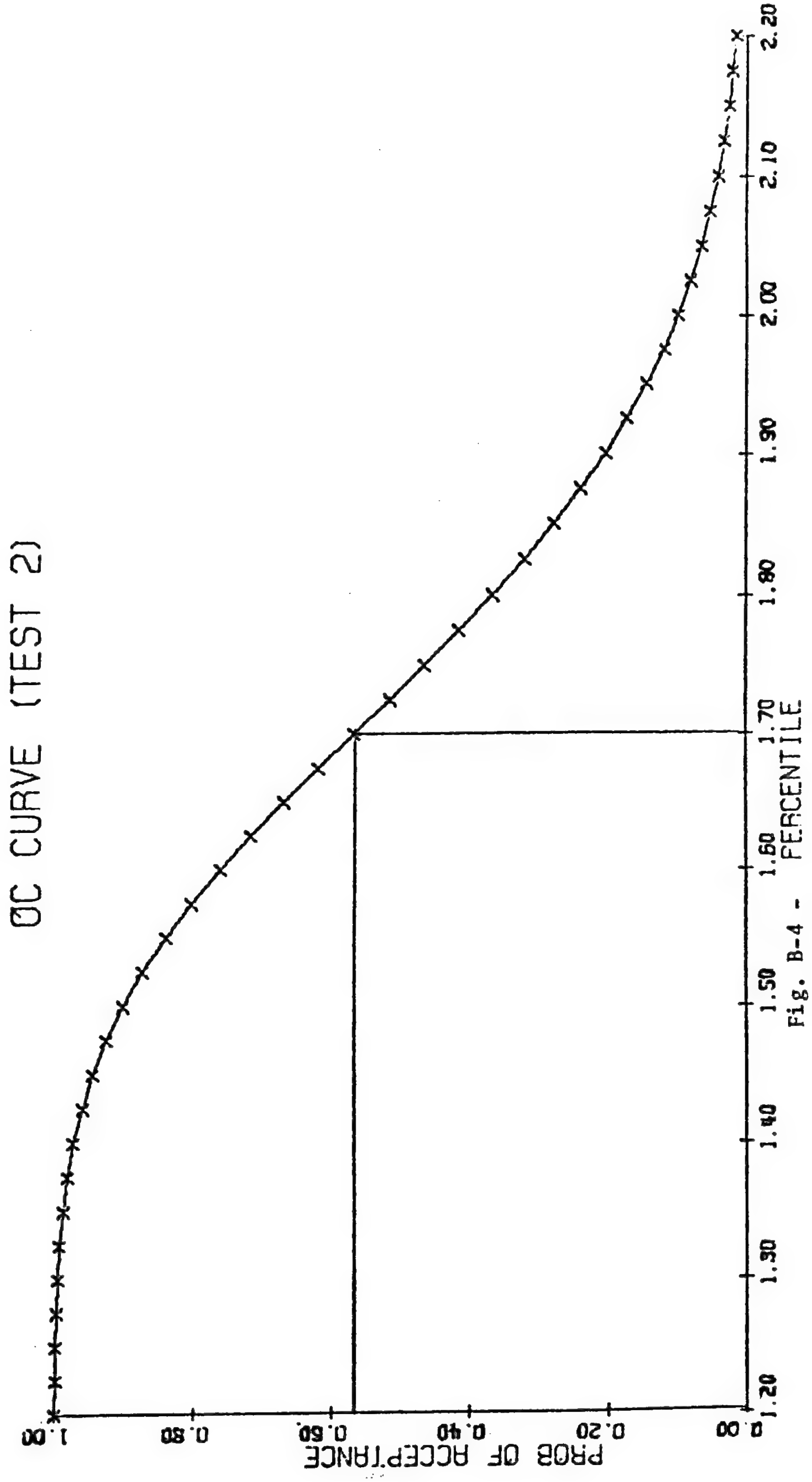

ØC CURVE (TEST 2)
PROB OF ACCEPTANCE
1.00
0.80
0.60
0.40
0.20
0.00
PERCENTILE
1.20
1.30
1.40
1.50
1.60
1.70
1.80
1.90
2.00
2.10
2.20

Fig. B-4 -

TEST METHOD 3

TEST ON CRITICAL MAINTENANCE TIME OR MANHOURS

B.40 General - This test provides for the demonstration of maintainability when the requirement is specified in terms of both a required critical maintenance time (or critical manhours) (X_{p_1}) and a design goal value (X_{p_0}) (or when the requirement is stated in terms of a required critical maintenance time (X_{p_1}) and a design goal value (X_{p_0}) is chosen by the contractor). The test is distribution-free and is applicable when it is desired to establish controls on a critical upper value on the time or manhours to perform specific maintenance tasks. In this test both the null and alternate hypothesis refer to a fixed time and the percentile varies. It is different from Test Method 2 where the percentile value remains fixed and the time varies.

B.40.1 Assumptions - No specific assumption is necessary concerning the distribution of maintenance time or manhours.

B.40.2 Hypothesis - H_0: $T = X_{p_0}$ (3-1)

$(p_1 > p_0)$

H_1: $T = X_{p_1}$ (3-2)

For specified α and β:

Illustration - H_0: 30 min. $= X_{0.50}$ = 50th percentile (median)

H_1: 30 min. $= X_{0.75}$ = 25th percentile

B.40.3 Sample Size, n, and Acceptance Number, c - The normal approximation to the binomial distribution is employed to find n and c when p_0 is not a small value. Otherwise, the Poisson approximation is employed. The equations for n and c are as follows:

For $0.20 \leq p_0 \leq 0.80$ $(p_i = 1 - Q_i)$

$$n = \left[\frac{Z_\beta\sqrt{p_1Q_1} + Z_\alpha\sqrt{p_0Q_0}}{p_1 - p_0}\right]^2 \quad \text{(Use next higher integer value.)} \quad (3\text{-}3)$$

$$c = n\left[\frac{Z_\beta p_0\sqrt{p_1Q_1} + Z_\alpha p_1\sqrt{p_0Q_0}}{Z_\alpha\sqrt{p_0Q_0} + Z_\beta\sqrt{p_1Q_1}}\right] \quad \text{(Use next lower integer value.)} \quad (3\text{-}4)$$

For $p_0 < 0.20$

For this case n and c can be found from the following two equations:

$$\sum_{r=0}^{c} \frac{e^{-np_0}\,(np_0)^r}{r!} \geq 1-\alpha \qquad (3\text{-}5)$$

$$\sum_{r=0}^{c} \frac{e^{-np_1}\,(np_1)^r}{r!} \leq \beta \qquad (3\text{-}6)$$

Table B-I provides sampling plans for various α and β risks and ratios p_1/p_0 when $p_0<0.20$.

B.40.4 Decision Procedure. Random samples of maintenance times are taken, yielding n observations $X_1, X_2, \ldots, X$. The number of such observations exceeding the specified time T is counted. This number is called r.

$$\text{Accept } H_0 \text{ if } r \leq c. \qquad (3\text{-}7)$$

$$\text{Reject } H_0 \text{ if } r > c. \qquad (3\text{-}8)$$

B.40.5 Discussion. In the development of the decision criteria and sample size, equations for this test, the normal or Poisson approximation to the binomial distribution is used.

B.40.6 Example. A median value of 30 minutes is considered acceptable whereas if 30 minutes is the 25th percentile then this is considered unacceptable. The following hypotheses result: ($\alpha = \beta = .10$)

H_0: 30 minutes = $X_{0.50}$ = 50th percentile median

H_1: 30 minutes = $X_{0.75}$ = 25th percentile

Then $Z_\alpha = Z_\beta = 1.28$, $p_0 = .50$, $p_1 = .75$ using equations 3-3 & 3-4.

$$n = (1.28)^2 \left[\frac{\sqrt{(.75)(.25)} + \sqrt{(.50)(.50)}}{(.25)}\right]^2 \approx 23$$

and,

$$c = 23 \left[\frac{(1.28).5\sqrt{(.75)(.25)} + 1.28\,(.75)\sqrt{(.50)\,(.50)}}{1.28\sqrt{(.50)(.50)} + 1.28\sqrt{(.75)(.25)}}\right] \approx 14$$

B.40.7 OC Curve - The OC curve for Test Method 3 for this example is given in Figure B-5. It gives the probability of acceptance for values of probability p, varying from 0.3 to 1.0. Here X_p is (1-p) th percentile. Thus, if the true value of the given critical maintenance time is 40th percentile, i.e., if the value of p is 0.6, then the probability that a demonstration will end in acceptance is 0.61 as seen from Fig. B-5.

TABLE B-I

SAMPLING PLANS FOR SPECIFIED p_0, p_1, α, and β
WHEN p_0 IS SMALL (e.g., $p_0 < 0.20$)

$k = \frac{p_1}{p_0}$	$\alpha = 0.05$						$\alpha = 0.10$						$\alpha = 0.20$					
	$\beta = 0.05$		$\beta = 0.10$		$\beta = 0.20$		$\beta = 0.05$		$\beta = 0.10$		$\beta = 0.20$		$\beta = 0.05$		$\beta = 0.10$		$\beta = 0.20$	
	c	D	c	D	c	D	c	D	c	D	c	D	c	D	c	D	c	D
1.5	66	54.1	54	43.4	39	30.2	51	43.0	40	33.0	29	23.2	36	31.8	27	23.5	17	14.4
2	22	15.7	18	12.4	14	9.25	17	12.8	14	10.3	10	7.02	12	9.91	9	7.29	6	4.73
2.5	13	8.46	10	6.17	8	4.70	10	7.02	8	5.43	6	3.90	7	5.58	5	3.34	3	2.30
3	9	5.43	7	3.98	6	3.29	7	4.66	5	3.15	4	2.43	4	3.09	3	2.30	2	1.54
4	6	3.29	5	2.51	4	1.97	4	2.43	3	1.75	2	1.10	3	2.30	2	1.54	1	0.824
5	4	1.97	3	1.37	3	1.37	3	1.75	2	1.10	2	1.10	2	1.54	1	0.824	1	0.824
10	2	0.818	2	0.818	1	0.353	1	0.532	1	0.532	1	0.532	1	0.824	1	0.824	0	0.227

To find the sample size n, for given p_0, p_1, α, and β, divide the appropriate D value by p_0 and use the greatest integer less than the quotient. Example: $p_0 = 0.05$, $p_1 = 0.20$ $\alpha = 0.10$, $\beta = 0.05$, and $k = \frac{0.20}{0.05} = 4$. Then $n = \frac{D}{0.05} = \frac{2.43}{0.05} = 48$. The acceptance number is $c = 4$.

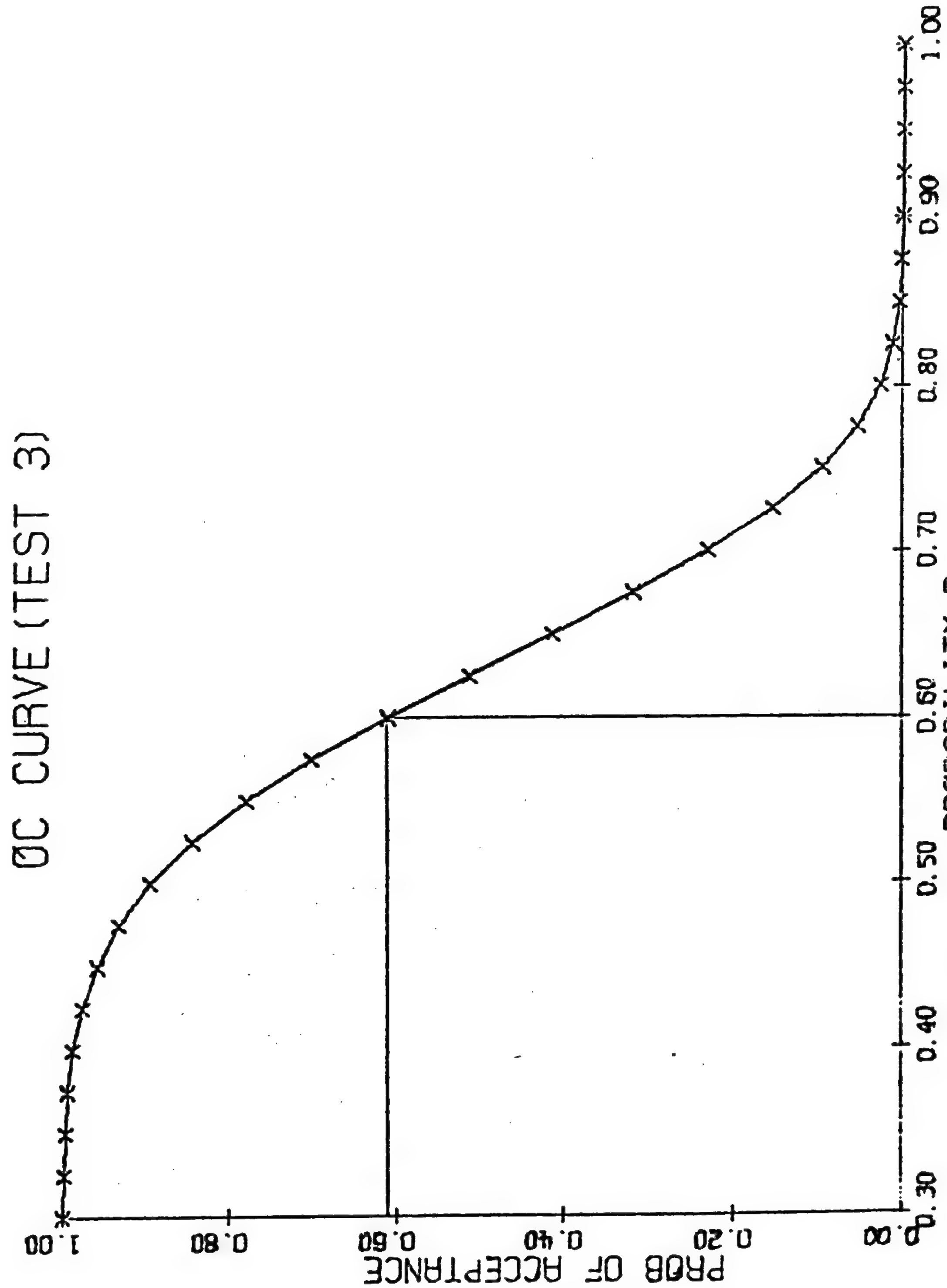

ØC CURVE (TEST 3)
PROB OF ACCEPTANCE
1.00
0.80
0.60
0.40
0.20
0.00
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
PROBABILITY, P

Fig. -5 -

TEST METHOD 4

TEST ON THE MEDIAN (ERT)

B.50 General - This method provides for demonstration of maintainability when the requirement is stated in terms of an equipment repair time (ERT) median, which will be specified in the detailed equipment specification.

B.50.1 Assumption - This method assumes the underlying distribution of corrective maintenance task times is lognormal.

B.50.2 Sample Size - The sample size required is 20. This sample size must be used to employ the equation described in this test method.

B.50.3 Task Selection and Performance - Sample tasks shall be selected in accordance with the procedure outlined in Appendix "A". The duration of each shall be recorded and used to compute the following statistics:

$$\text{Log } MTTR_G = \frac{\sum_{i=1}^{n_c} (\text{Log } X_{ci})}{n_c} \quad (4\text{-}1)$$

$$S = \sqrt{\sum_{i=1}^{n_c} \frac{(\log X_{ci})^2}{n_c} - (\log MTTR_G)^2} \quad (4\text{-}2)$$

All logarithms will be taken to the base 10

Where: $MTTR_G$ is the measured geometric mean time to repair. It is the equivalent to the $\widetilde{M}_{ct}$ used in other plans included in this document.

B.50.4 Decision Procedure - The equipment under test will be considered to have met the maintainability requirement (ERT) when the measured geometric mean-time-to-repair ($MTTR_G$) and standard deviation(S) as determined in 50.3 satisfies the following expression:

$$\text{Accept if } \log MTTR_G \leq \log ERT + .397(S) \quad (4\text{-}3)$$

where: log ERT = logarithm of the equipment repair time
log $MTTR_G$ = the value determined in accordance with para. 50.3
S = the value determined in accordance with para. 50.3

B.50.5 Discussion - The value of equipment repair time (ERT) to be specified in the detailed equipment specification should be determined using the following expression:

$$ERT \text{ (specified)} = 0.37 \, ERT_{max} \quad (4\text{-}4)$$

where:

ERT_{max} = the maximum value of ERT that should be accepted no more than 10 percent of the time.

0.37 = a value resulting from application of "student's t" operating characteristics that assures a 95 percent probability that an equipment having an acceptable ERT will not be rejected as a result of the maintainability test when the sample size is 20, and assuming a population standard deviation (σ) of 0.55.

B.50.5.1 Derivation of Criteria - The following are brief explanations of the derivations of various criteria specified herein, and are intended for information purposes only. The acceptance criterion, $\log MTTR_G \leq \log ERT \neq 0.397(S)$, assures a probability of .95 of accepting an equipment or **system** as a result of one test when the true geometric mean-time-to-repair is equal to the specified equipment repair time (that is, a probability of 0.05 of rejecting an equipment or systems having a true $MTTR_G$ equal to the specified ERT). This was derived by using conventional methods for establishing acceptance criteria. The conventional methods for determining acceptance based on the measured mean of a small sample (that is, sample size less than 30), and when the true standard deviation (σ) of the population can only be estimated, is to compare the measured mean with the desired mean using the expression:

$$t = \frac{(\bar{x} - \bar{x}_o)}{S} \sqrt{n_c - 1}$$

where:

$$S = \sqrt{\frac{\Sigma_i (x_i - \bar{x})^2}{n_c}}$$ or the standard deviation of the sample;

$\bar{x}$ = the sample or measured mean

$\bar{x}_o$ = the specified or desired mean

n_c = the sample size

x_i = the value of one measurement of the sample

The decision to accept the product will be made when the test results give a value of t, as calculated from the above expression numerically less than or equal to a value of t obtained from "student's t"

distribution tables at the established level (that is, 0.99, 0.95, 0.90, and so forth) of acceptance and the appropriate sample size. The "student's t" distribution tables (for a single tailed area) give a value of t = 1.729 at the 0.95 acceptance level when the sample size is 20 (that is, 19 degrees of freedom). The table for single tailed area is used since only values of $MTTR_G$ greater than the specified ERT are critical. An equipment with any value of $MTTR_G$ lower than the specified ERT is acceptable. To apply the expression for "t" to the maintainability test, let $\overline{x}_o$ = log ERT (specified), $\overline{x}$ = log $MTTR_G$ (measured), S = the measured standard deviation of the logarithms of the sample of measured repair time, and n_c = the sample size of 20. The measured $MTTR_G$ is then compared with the desired ERT by calculating the value of t using the expression below:

$$t = \frac{(\log MTTR_G - \log ERT)}{S} \sqrt{19}$$

The equipment under test can be acceptable if the value of t calculated from the expression above is equal to or less than + 1.729 (the value of t from the "student's t" distribution tables at an acceptable level of .95 when the sample size is 20). Therefore, the equipment should be accepted when:

$$\sqrt{19}\ \frac{(\log MTTR_G - \log ERT)}{S} \leq +1.729.$$

Upon rearranging and simplifying this expression, the acceptance criterion is obtained as shown below:

$$\log MTTR_G - \log ERT \leq \frac{1.729(S)}{\sqrt{19}}$$

$$\log MTTR_G \leq \log ERT + .397(S)$$

(NOTE: Reference - "Introduction to Mathematical Statistics," P. Hoel, J. Wiley and Sons, Inc., 2nd Edition, 1954, PP. 222-229)

TEST METHOD 5

TEST ON CHARGEABLE MAINTENANCE DOWNTIME PER FLIGHT

B.60 General - Because of the relatively small size of the demonstration fleet of aircraft and administrative and operational differences between it and fully operational units, operational ready rate or availability cannot be demonstrated directly. However, a contractual requirement for chargeable downtime per flight can be derived analytically from an operational requirement of operational ready rate or availability. This chargeable downtime per flight can be thought of as the allowable time (hours) for performing maintenance given that the aircraft has levied on it a certain availability or operational readiness requirement. The requirement for chargeable downtime per flight will be established using the procedure in B.60.3. Chargeable downtime per flight can then be demonstrated using the procedures in B.60.5.

B.60.1 Definitions - The following definitions apply to this test method:

A = Availability - A measure of the degree (expressed as a probability) to which an aircraft is in the operable and committable state at the start of the mission, when the mission is called for at an unknown (random) point in time. In this standard, availability is considered synonomous with operational readiness. The aircraft is not considered to be in an operable and committable state when it is being serviced and is undergoing maintenance (see MIL-STD-721B).

TOT = Total Active Time in Hours.

Active Time = That time during which an aircraft is assigned to an organization for the purpose of performing the organizational mission. It is time during which:

1. The aircraft is flying or ready to fly.
2. Maintenance is being performed.
3. Maintenance is delayed for supply or administrative reasons.

DUR = Daily Utilization Rate - The number of flying hours per day.

AFL = Average Flight Length - Flying hours per flight.

NOF = Number of Flights per Day.

DT = Downtime - Time (in hours) during which the aircraft is not ready to commence an assigned mission (i.e., have the flight crew board the aircraft).

CMDT = Chargeable Maintenance Downtime - Time (in hours) during which maintenance personnel are working on the aircraft, except when the only work being done would fall under the nonchargeable maintenance downtime (NCMDT) category.

NCMDT = Nonchargeable Maintenance Downtime - Time (in hours) during which the aircraft is not available for immediate flight but the only maintenance being performed is not chargeable. It would include the following:

1. To correct maintenance or operational errors not attributable to technical orders, contractor furnished training or faulty design.

2. Miscellaneous tasks such as keeping of records or taxiing or towing the aircraft to or from other than the work center area.

3. Repair of accident or battle damage.

4. Modification tasks.

5. Maintenance caused by test instrumentation.

DDT = Delay Downtime - Downtime (in hours) during which maintenance is required but no maintenance is being performed on the aircraft for supply or administrative reasons. It would include the following:

1. Supply Delay Downtime.

   a. Not Operationally Ready Supply (NORS) time.

   b. Item obtainment time from other than the work center area.

2. Administrative Delay Downtime.

   a. Personal breaks such as coffee or lunch.

   b. No maintenance people available for administrative reasons.

α = the producer's risk: The risk that the producer (contractor) must take that the hypothesis that a true mean = M_0 will be rejected even though it is true. The desirable value of α must be determined by judgement and agreed upon by the procuring activity and the contractor. All other things being equal, a smaller value of α will require a larger sample size.

M = The maximum mean chargeable maintenance downtime per flight.

M_0 = The required mean CMDT per flight.

$M-M_0$ = The difference between the maximum mean (M) of the parameter being tested and the specified mean (M_0). This value must be determined in conjunction with a value for β, the consumer's risk. M is a value, greater (worse) than the specified mean, which the consumer is willing to accept, but only with a small risk or probability (β). If the true mean is in fact equal to the value of M selected, the hypothesis the true mean = M_0 will be accepted, although erroneously, 100 β percent of the time.

β = the consumer's risk. The risk, which the consumer is willing to take, of accepting the hypothesis that the true mean = M_0 when in fact the true mean = M. All other things being equal, a smaller value of β will require a larger sample size.

σ = the true standard deviation of the parameter (CMDT per flight) being tested. This value, unless it is a specification requirement, will not be known, but an estimate must be made. (It is assumed that both M and M_0 will have the same value of σ.) The contractor's maintainability math model, previous models, or previous data may be used. All other things being equal a larger value of σ will require a larger sample size.

B.60.2 <u>Assumptions</u> - This method requires no assumption as to the probability distribution of chargeable downtime per flight. The method is valid only if the Central Limit Theorem applies, which means that the sample size (number of flights) must be large enough for this theorem to apply. The sample size shall be at least 50, but the actual size is to be determined in accordance with para. B.60.4.

B.60.3 <u>Derivation of CMDT per Flight from Availability</u>.- The requirement for CMDT per flight which will be demonstrated will be determined using the following mathematical derivation.

$$A = 1 - \frac{CMDT + NCMDT + DDT}{TOT} \qquad (5\text{-}1)$$

$$A(TOT) = TOT - CMDT - NCMDT - DDT \qquad (5\text{-}2)$$

$$CMDT = TOT - A(TOT) - NCMDT - DDT \qquad (5\text{-}3)$$

$$\frac{CMDT}{NOF} = \frac{TOT - A(TOT) - NCMDT - DDT}{NOF} \qquad (5\text{-}4)$$

but,

$$NOF = \frac{TOT\ (DUR)}{24\ (AFL)} \qquad (5\text{-}5)$$

therefore,

$$\frac{CMDT}{NOF} = \frac{24\ (AFL)}{DUR} - \frac{A(24)(AFL)}{DUR} - \frac{NCMDT}{NOF} - \frac{DDT}{NOF} \qquad (5\text{-}6)$$

$\frac{CMDT}{NOF}$ = CMDT per flight, which will be demonstrated.

Values for UR and AFL should be those planned for the aircraft during operational use. Values for $\frac{NCMDT}{NOF}$ and $\frac{DDT}{NOF}$ are a function of the operational environment. They will be provided to the contractor in the RFP or, if not, will be provided by him in his proposal. The value for availability or operational ready rate will be provided in the RFP.

Example: Following is an example of how a requirement for CMDT per flight $\frac{CMDT}{NOF}$ will be derived:

Required A = 0.75

DUR = 2 hours per day

AFL = 4 hours per flight

$\frac{NCMDT}{NOF}$ = 0.2 hours per flight

$\frac{DDT}{NOF}$ = 1.0 hours per flight

Then,

$$\frac{CMDT}{NOF} = \frac{24(4)}{2} - \frac{(0.75)(24)(4)}{2} - 0.2 - 1.0$$

$$\frac{CMDT}{NOF} = 48 - 36 - 0.2 - 1.0$$

$$\frac{CMDT}{NOF} = 10.8 \text{ hours per flight}$$

B.60.4 Sample Size - Since the Central Limit Theorem is applied, the expected distribution of the means will take on a normal distribution as in Figure B-6. If the true mean is equal to M_o and a particular α is desired the upper distribution (the mean of the distribution will equal M_o) will apply. It is on this basis that an acceptance rule is generated to the effect that if $\overline{X}$ is found to be equal to or less than the value $M_o + \frac{Z_\alpha \sigma}{\sqrt{n}}$ the item is to be accepted.

If the true mean is equal to M (which is greater than M_o) the distribution of means will take on a normal distribution with a mean of M as shown in the lower distribution. The value to be used as an acceptance criterion $M_o + \frac{Z_\alpha \sigma}{\sqrt{n}}$ corresponds and is equal to a value:

$\left(M + \frac{Z_{\alpha'} \sigma}{\sqrt{n}}\right)$ where α' is a new confidence level

$$M_o + \frac{Z_\alpha \sigma}{\sqrt{n}} = M + \frac{Z_{\alpha'} \sigma}{\sqrt{n}} \qquad (5\text{-}7)$$

where $M = M_o + (M - M_o)$ (5-8)

$$M_o + \frac{Z_\alpha \sigma}{\sqrt{n}} = M_o + M - M_o + \frac{Z_{\alpha'} \sigma}{\sqrt{n}} \qquad (5\text{-}9)$$

or simplifying, the sample size (n) requirement is:

$$n = \frac{(Z_\alpha - Z_{\alpha'})^2}{\left(\frac{M-M_o}{\sigma}\right)^2} = \frac{(Z_\alpha - Z_{(1-\beta)})^2}{\left(\frac{M-M_o}{\sigma}\right)^2} \qquad (5\text{-}10)$$

If this expression should result in n less than 50, then a sample of 50 shall be used.

α = Prob. of rejection if true mean equals M.

$1 - \alpha' = \beta$ = Prob. of acceptance if true mean equals M.

Z_α, $Z_{(1-\beta)}$ = standardized normal deviated as defined.

See table below for relationships between Zw and α & β

$w = \alpha$ or $1 - \beta$

Z_w	.01	.05	.1	.15	.2	.3	.7	.8	.85	.9	.95	.99
	2.33	1.65	1.28	1.04	.84	.52	-.52	-.84	-1.04	-1.28	-1.65	-2.33

$Z_w = Z_\alpha$ or $Z_{(1-\beta)}$

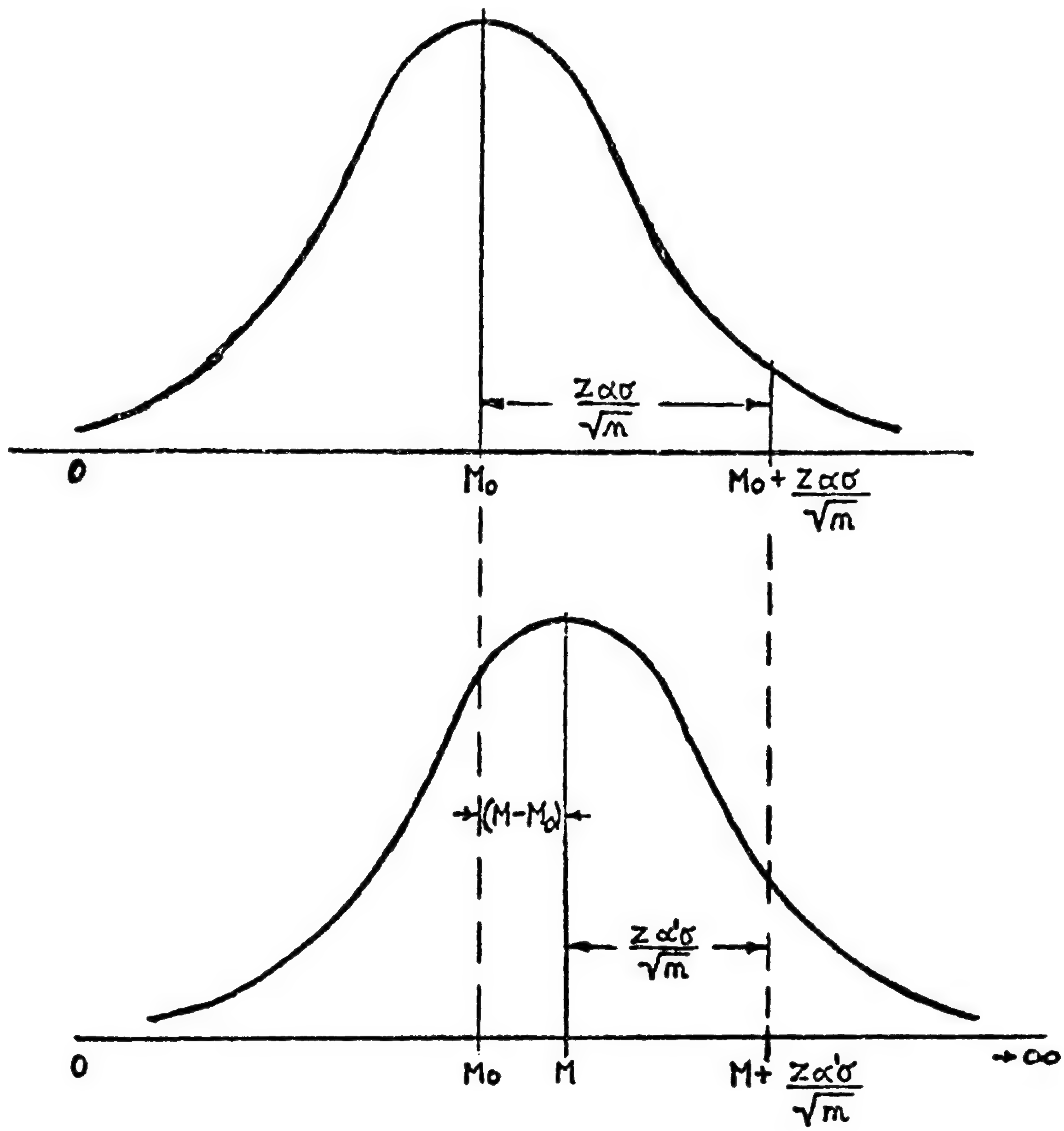
Example: Suppose for a requirement of $M_0 = 2.0$, the following statistical test parameters were agreed to by the procuring activity and the contractor:

$\alpha = 0.10$; $Z_\alpha = 1.28$; $\beta = 0.10$; $Z_{1-\beta} = -1.28$; $M - M_0 = 0.30$; $\sigma = 1.0$;

$$\frac{M - M_0}{\sigma} = 0.3$$

Using equation 5-10:

$$n = \frac{(1.28 + 1.28)^2}{(.3)^2} = \frac{(2.56)^2}{(.3)^2} = \frac{6.57}{.09} = 73$$



Where: $\left(M + \frac{Z\alpha'\sigma}{\sqrt{m}}\right)$ corresponds to the value $\left(M_o + \frac{Z\alpha\sigma}{\sqrt{m}}\right)$

Fig. B-6 Distribution of Means

B.60.5 Decision Procedure - The chargeable maintenance downtime (X_i) after each flight will be measured and, at the end of the test, the total chargeable downtime will be divided by the total number of flights to obtain ($\overline{X}$) the sample mean CMDT and the sample standard deviation (s) of CMDT.

$$\overline{X} = \frac{\sum_{i=1}^{NOF} X_i}{NOF} \qquad (5\text{-}11)$$

$$s = \sqrt{\sum_{i=1}^{NOF} \frac{(X_i - \overline{X})^2}{NOF-1}} = \sqrt{\frac{1}{(NOF-1)} \sum_{i=1}^{NOF} X_i^2 - (NOF)\overline{X}^2} \qquad (5\text{-}12)$$

Accept if: $\overline{X} \leq M_o + \frac{Z_\alpha S}{\sqrt{NOF}}$ (5-13)

Reject if: $\overline{X} > M_o + \frac{Z_\alpha S}{\sqrt{NOF}}$ (5-14)

TEST METHOD 6

TEST ON MANHOUR RATE

B.70 General - This test for demonstrating manhour rate (manhours per flight hour) is based on a determination during Phase II test operation of the total accumulative chargeable maintenance manhours and the total accumulative demonstration flight hours. The demonstrated manhour rate is calculated as:

$$\text{Manhour Rate} = \frac{\text{Total Chargeable Maintenance Manhours}}{\text{Total Demonstration Flight Hours}} \qquad (6\text{-}1)$$

If the demonstrated manhour rate is less than or equal to the manhour rate requirement plus a maximum value (ΔMR), by which the demonstrated manhour rate will be permitted to differ from the required manhour rate, then the requirement has been met. Δ MR will be provided, by the procuring activity, as a percentage of the system manhour rate requirement and will be determined based upon such considerations as the expected Phase II duration, and prior experience with similar systems. It is recognized that this demonstration method is nonstatistical in nature and does not allow the determination of quantitative producer's and consumer's risk levels. It is for this reason that the ΔMR is provided (in a subjective manner) to minimize the producer's risk.

B.70.1 Normally, all maintenance performed by approved test maintenance personnel during Phase II and documented in appropriate maintenance reports will be the source of data for identifying chargeable maintenance manhours. The procuring activity may elect to terminate the demonstration prior to Phase II completion if sufficient data are collected to project that the requirement will be met.

B.70.2 The manhour rate requirement must pertain to the aircraft configuration provided for in the contract. For Phase II flights conducted with a configuration other than this, an appropriate amount of chargeable manhours will be included in calculating the total chargeable manhours. This amount will be based upon the predicted manhour rate associated with the equipment not installed.

B.70.3 Care must be exercised in assuring that the predicted manhour rate pertains to flight time and not equipment operating time. The contractor must develop appropriate ratios of equipment operating time to flight time.

TEST METHOD 7

TEST ON MANHOUR RATE - (USING SIMULATED FAULTS)

B.80 General. This test for demonstrating manhour rate (manhours per operating hour) is based on (a) the predicted total failure rate of the equipment used in the formulation of Table I, Appendix A, (b) the total accumulative chargeable maintenance manhours and the total accumulative simulated demonstration operating hours. The demonstrated manhour rate is calculated as:

$$\text{Manhour Rate} = \frac{\text{Total Chargeable Maintenance Hours}}{\text{Total Operating TIme}} = \frac{\sum_{i=1}^{n} X_{ci} + (PS)}{T} \qquad (7\text{-}1)$$

where:

X_{ci} = Manhours for corrective maintenance task i

n = Number of corrective maintenance tasks sampled, n shall not be less than 30

MTBF = MTBF of the unit (value used in development of Table I)

(PS) = Estimated average total manhours which would be required for preventive maintenance during a period of operating time equal to n·(MTBF) hours

$\sum_{i=1}^{n} \frac{X_{ci}}{n} = \overline{X}_c$ = Average number of corrective maintenance manhours per corrective maintenance task

T = Operating time

B.80.1 Discussion. When maintenance tasks are simulated as in Table 1, $T = n\cdot(MTBF)$ where $\frac{1}{MTBF} = \lambda_T$, the total failure rate of the equipment in question.

$$\frac{\sum_{i=1}^{n} X_{ci} + (PS)}{T} = \frac{\sum_{i=1}^{n} X_{ci} + (PS)}{n\cdot(MTBF)} = \frac{1}{MTBF}\left[\overline{X}_c + \frac{(PS)}{n}\right] \qquad (7\text{-}2)$$

All components of (7-2) with the exception of $\overline{X}_c$ can be considered constants. $\overline{X}_c$ can be considered a normally distributed variable when n is large (due to the Central Limit Theorem) with Variance = $\frac{d^2}{n}$.

If $\overline{X}_c$ is normally distributed it can be shown that the function:

$\frac{1}{(MTBF)} [\bar{X}_c + \frac{PS}{n}]$ is also normally distributed around the mean of the manpower rate with Variance = $(\frac{1}{n}) (\frac{d}{MTBF})^2$;

assuming $d = \hat{d}$.

B.80.2 Decision Procedure. Therefore, if the manhour rate requirement = μ_R.

Accept if:

$$\bar{X}_c \leq \mu_R \text{ (MTBF)} - (\frac{PS}{n}) + Z_\alpha \frac{\hat{d}}{n} \qquad (7\text{-}3)$$

Where α denotes producer's risk.

TEST METHOD 8

TEST ON A COMBINED MEAN/PERCENTILE REQUIREMENT

B.90 General - This test provides for the demonstration of maintainability when the specification is couched in terms of a dual requirement for the mean and either the 90th or 95th percentile of maintenance times when the distribution of maintenance time is lognormal.

B.90.1 Assumptions - For use as a dual mean and 90th or 95th percentile requirement the mean must be greater then 10 and less than 100 units of time; the ratio of the 90th percentile maximum value to the value of the mean must be less than two; the ratio of the 95th percentile maximum value to the value of the mean must be less than three.

	Maximum Ratio of Percentile to Mean
90th Percentile Value	2
95th Percentile Value	3

Distribution assumptions are as defined in B.90.

B.90.2 Discussion - The test method actually demonstrates the 61st percentile value of maintenance time in combination with either the 90th or 95th percentile values of maintenance time rather than the mean value of maintenance time in combination with either the 90th or 95th percentile values of maintenance time. However, because of the particular characteristic of the lognormal distribution once a 61st percentile value of maintenance time less than X_1 and a 90th or 95th percentile value less than X_2 has been demonstrated, for all practical purposes a mean value of less than approximately X_1 and a 90th or 95th percentile value less than X_2 have likewise been demonstrated.

A dual requirement on maintainability, assuming a lognormal distribution of repair times, of a maximum value of the Mean in conjunction with either the maximum value of the 90th or 95th percentile of repair time (to be referred to as M_{max}) results in the definition of various combinations of θ's and σ's which are acceptable to the dual requirement. (A complete technical description of a lognormal distribution is provided by knowledge of θ & σ, hence, all possible lognormal distributions acceptable to the requirements are defined through definition of all possible acceptable values of θ and σ.) See Figure B-8A which defines the acceptable combinations of θ & σ for a Mean of 30 minutes and a 95th percentile (M_{max}) of 60 minutes.

For the lognormal distribution it is also possible to structure a dual requirement made up of the maximum values of two percentiles (for example, the 61st percentile of repair time shall be a maximum of 30 minutes and the 95th percentile of repair time shall be a maximum of 60 minutes). This dual requirement also results in the definition of various combinations of acceptable values of θ and σ. See Figure B-9B. If a dual percentile requirement could be structured such that the set of acceptable values of θ and σ defined were almost identical to the set of values of θ and σ defined

for a given dual Mean and percentile requirement then a demonstration of that dual percentile requirement would in reality also demonstrate the attainment of the dual Mean and M_{max} requirement. For this particular instance it has been found that under the assumptions listed above, almost identical acceptable values of θ and σ are provided for a combined Mean and M_{max} requirement and a combined 61st percentile (where the value of the 61st percentile is taken equal to the specified value of the Mean) and M_{max} requirement. See Figure B-8B which defines the values of θ and σ acceptable to a dual 61st percentile (where the value of the 61st percentile is taken equal to a specified mean of 30 minutes) and 95th percentile (where the maximum value of the 95th percentile, M_{max}, is given as 60 minutes) and Figure B-8C which is the superimposition of Figure B-8A on Figure B-8B.

Therefore, tests performed to demonstrate the attainment of both the percentiles in question actually demonstrates the attainment of values of θ & σ which are almost identically acceptable to a dual requirement of the Mean and M_{max}. It follows then that an accept decision relative to both percentiles would also approximately signify an accept decision for a dual Mean and M_{max} requirement.

Since both percentiles can be considered independent for practical purposes, the same samples can be used for demonstrating both percentiles, therefore, if desired the tests may be run simultaneously.

B.90.3 Procedure - Sample tasks shall be selected with respect to the procedure defined for variable sample/sequential tests. The same sample tasks may be used simultaneously in the demonstration of both the Mean and M_{max} requirements. Table 1*, Table 2*, Table 3* (which are based upon the sequential probability ratio test of proportion) define the accept/reject criteria for the values of the required mean, M_{max} (when defined as the maximum 90th percentile value), M_{max} (when defined as the maximum 95th percentile value), respectively. The number of observations greater than and less than the required values of the Mean and M_{max} shall be cumulated separately and compared to the decision values shown in the tables applicable to the two requirements. When one plan provides an accept decision, attention to that plan shall be discontinued. The second plan shall continue until a decision is reached. The equipment shall be rejected when a decision to reject on either plan has occurred regardless of the status of the other plan. The equipment shall be accepted only when an accept decision has been reached on both plans. If no accept or reject decision has been made after 100 observations, the following rule shall apply:

NOTE: *Tables 1, 2 & 3 are appropriate to Test Plans A_1, B_1 and B_2, respectively.

Plan A_1 - Accept only if 29 or less observations are more than the value of the required Mean.

Plan B_1 - Accept only if 5 or less observations are more than M_{max_c}.

Plan B_2 - Accept only if 2 or less observations are more than M_{max_c}.

It is recognized and accepted that truncation will somewhat modify probability of acceptance characteristics as described in the following section.

B.90.4 <u>The OC Curve</u> - The operating characteristic curve for the test procedure may be determined by mapping the probability of acceptance for various selected points on a diagram of the acceptable and unacceptable regions such as Figure B-8D. (Note that any point can be identified uniquely by the coefficient of Q, where Q = ln (required Mean), on the ordinate and the coefficient of $\sqrt{Q}$ on the abcissa - let the coefficient of Q be denoted as (C) and the coefficient of $\sqrt{Q}$ be denoted as (K) - for example, point B on Figure B-8D can be uniquely located at C = 3/4, K = .4). Each point is also representative of a particular lognormal distribution possessing unique percentiles for the values given for μ_1 (required maximum value for Mean) and M_{max}, respectively.

The probability of acceptance relative to any point is equal to the compound probability of passing the percentile test relative to μ_1 (Test A1) and passing the percentile test relative to M_{max} (Test B1 or B2).

Let P_{A1}, P_{B1}, P_{B2} be the probability of passing test A_1, B_1, B_2, respectively for any given unique combination of θ and σ (a particular point).

P_{A1}, P_{B1}, P_{B2} may be determined by calculating Y_{A1}, Y_{B1}, Y_{B2} from the following equations:

$$Y_{A1} = \frac{\sqrt{Q}\,(1-C)}{K} \qquad (7\text{-}1)$$

$$Y_{B1}=Y_{B2} = \frac{\ln M_{max}-CQ}{K\sqrt{Q}} \qquad (7\text{-}2)$$

and entering Figure B-8E (for Test A1) with the calculated value of Y_{A1} and Figure B-8F (for Test B_1) or Figure B-8G (for Test B_2) with the calculated value of Y_{B1} or Y_{B2}. The corresponding value of probability of acceptance, P_{A1}, and P_{B1} or P_{B2} (whichever of the B tests are appropriate) is read from each Figure and P_{A1} and the appropriate P_{B1} or P_{B2} value are multiplied. The result of this multiplication is the probability of acceptance of a unit having a particular θ and σ characteristic defined by (C) and (K).

Repeating the above for a number of points as in Figure B-8H defines an operating characteristic map relative to a given dual requirement. Note that probabilities of acceptance always decrease as the point is located upward or to the right and always increase as the point in consideration is located downward or to the left on the figure. Hence, sufficient knowledge of test characteristics can be generated by evaluating relatively few points.

TABLE 1

Plan (A_1)
Observations Exceeding the Value of the Mean
(or 61st percentile value)

# of Tasks OBSR (N)	Accept	Reject	# of Tasks OBSR (N)	Accept	Reject
5		5	55	12	↕
6		6	56	13	20
7		↕	57	↕	21
8		6	58	13	↕
9		7	59	14	21
10		↑	60	↑	22
11		↓	61	↓	↕
12	0	7	62	14	22
13	↕	8	63	15	23
14	0	↕	64	↕	↑
15	1	8	65	15	↓
16	↑	9	66	16	23
17	↓	↑	67	↕	24
18	1	↓	68	16	↕
19	2	9	69	17	24
20	↕	10	70	↑	25
21	2	↕	71	↓	↑
22	3	10	72	17	↓
23	↕	11	73	18	25
24	3	↕	74	↕	26
25	4	11	75	18	↕
26	↑	12	76	19	26
27	↓	↑	77	↕	27
28	4	↓	78	19	↕
29	5	12	79	20	27
30	↕	13	80	↑	28
31	5	↕	81	↓	↑
32	6	13	82	20	↓
33	↕	14	83	21	28
34	6	↕	84	↕	29
35	7	14	85	21	↕
36	↑	15	86	22	29
37	↓	↑	87	↑	30
38	7	↓	88	↓	↕
39	8	15	89	22	30
40	↕	16	90	23	31
41	8	↕	91	↕	↑
42	9	16	92	23	↓
43	↑	17	93	24	31
44	↓	↑	94	↕	32
45	9	↓	95	24	↕
46	10	17	96	25	32
47	↕	18	97	↑	33
48	10	↕	98	↓	↑
49	11	18	99	25	↓
50	↕	19	100	26	33
51	11	↕			
52	12	19			
53	↑	20			
54	↓	↕			

TABLE 2

Plan (B_1)

Observations Exceeding M_{max} - 90 Percentile

# of Tasks OBSR (N)	Accept	Reject	# of Tasks OBSR (N)	Accept	Reject
2		2	52		4
3			53		5
4			54		
5			55		
6			56		
7			57		
8			58		
9			59		
10			60		
11			61		
12			62		
13		2	63		
14		3	64	1	
15			65	2	
16			66		
17			67		
18			68		
19			69		
20			70		
21			71		
22			72		5
23			73		6
24			74		
25			75		
26	0		76		
27			77		
28			78		
29			79		
30			80		
31			81		
32			82		
33		3	83		
34		4	84	2	
35			85	3	
36			86		
37			87		
38			88		
39			89		
40			90		
41			91		
42			92		6
43			93		7
44			94		
45	0		95		
46	1		96		
47			97		
48			98		
49			99		
50			100	3	7
51					

TABLE 3

Plan (B_2)

Observations Exceeding M_{max} - 95 Percentile

# of Tasks OBSR (N)	Accept	Reject	# of Tasks OBSR (N)	Accept	Reject
2		2	52		
3			53		
4			54		
5			55		
6			56		
7			57	0	
8			58		
9			59		
10			60		
11			61		
12			62		
13			63		
14			64		
15			65		
16			66		
17			67		
18			68		
19			69		3
20			70		4
21			71		
22			72		
23			73		
24			74		
25			75		
26			76		
27		2	77		
28		3	78		
29			79		
30			80		
31			81		
32			82		
33			83		
34			84		
35			85		
36			86		
37			87		
38			88		
39			89		
40			90		
41			91		
42			92		
43			93		
44			94		
45			95		
46			96		
47			97		
48			98	0	
49			99	1	
50			100	1	4
51					

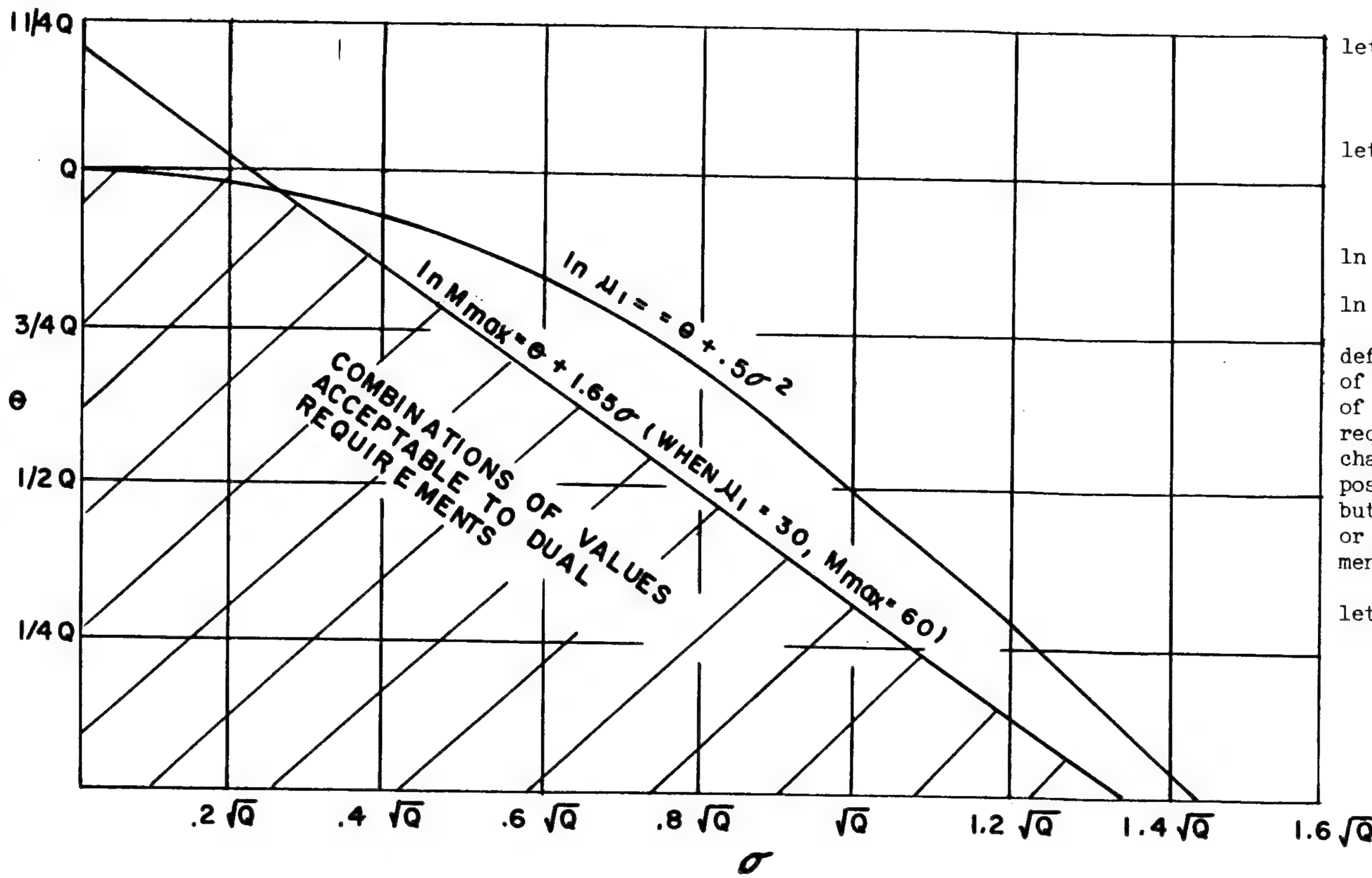


Figure B-8A

let μ_1 = required value of mean (maximum allowable)

let X_{p1} = maximum value of 95th percentile = M_{max}

$\ln \mu_1 \geq \theta + .5\sigma^2$

$\ln M_{max} \geq \theta + 1.65\sigma$

define all possible values of θ & σ which are capable of meeting or bettering the requirement (defines the characteristics of all possible lognormal distributions capable of meeting or bettering the requirements).

let $\ln \mu_1 = Q$

FIGURE B-8A

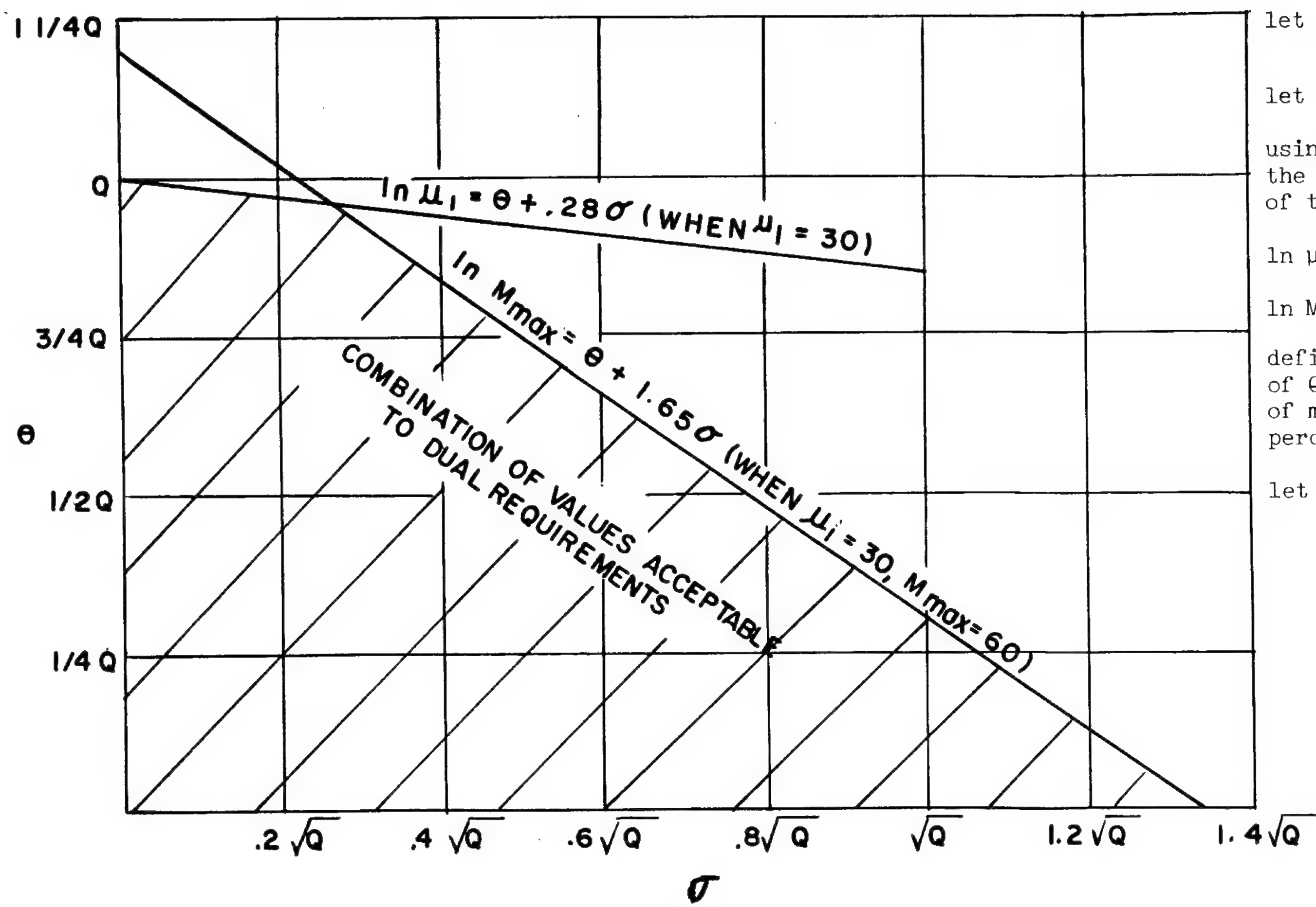


Figure B-8B

let μ_1 = required value of mean (max. allowable)

let X_{pl} = maximum value of 95th percentile = M_{max} using the required value for the mean as the maximum value of the 61st percentile.

$\ln \mu_1 \geq \theta + .28\,\sigma$

$\ln M_{max} \geq \theta + 1.65\,\sigma$

define all possible values of θ & σ which are capable of meeting the dual percentile requirement.

let $\ln \mu_1 = Q$

FIGURE B-8B

SUPERIMPOSITION OF FIGURES B-8A AND B-8B

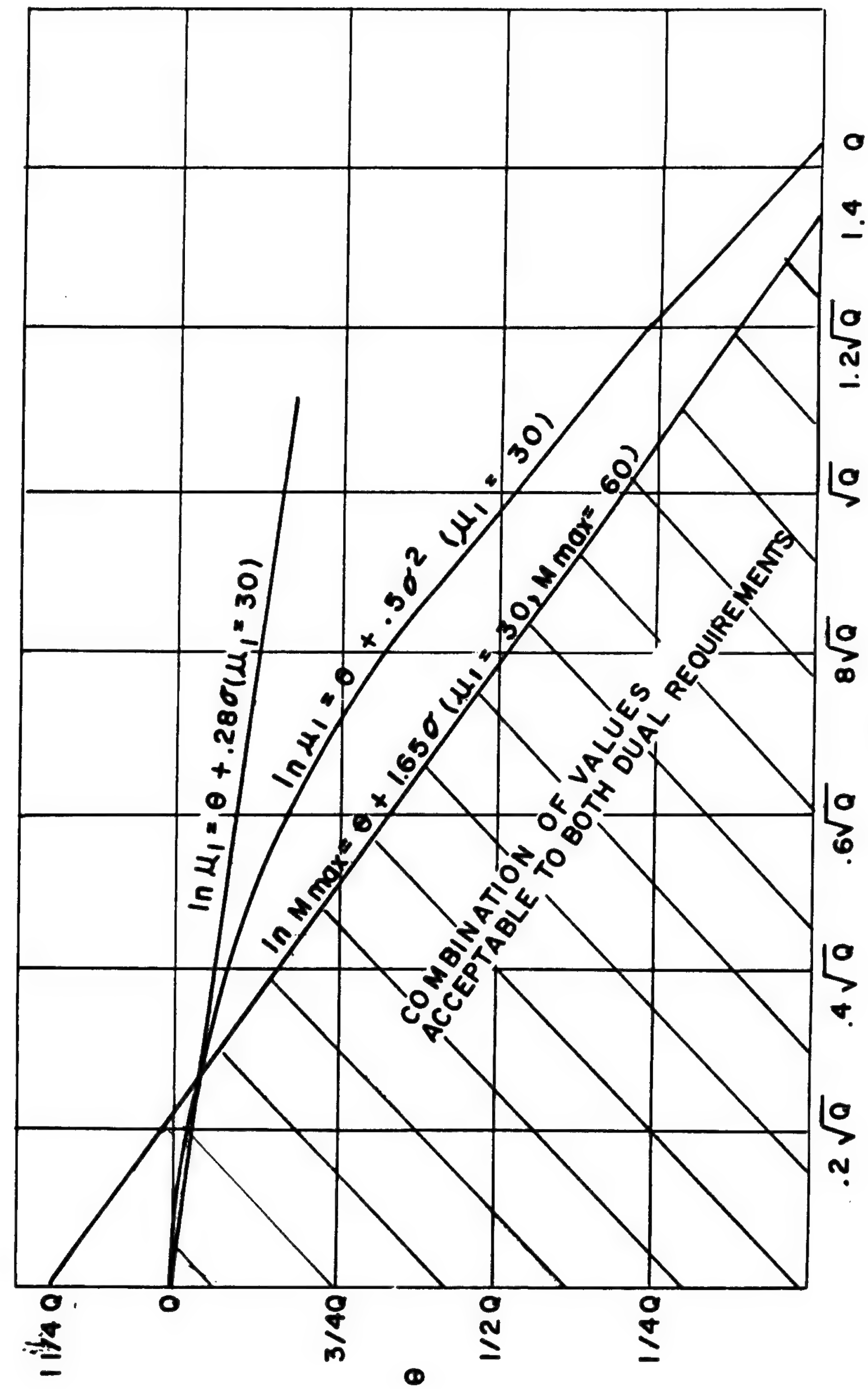


Figure B-8C

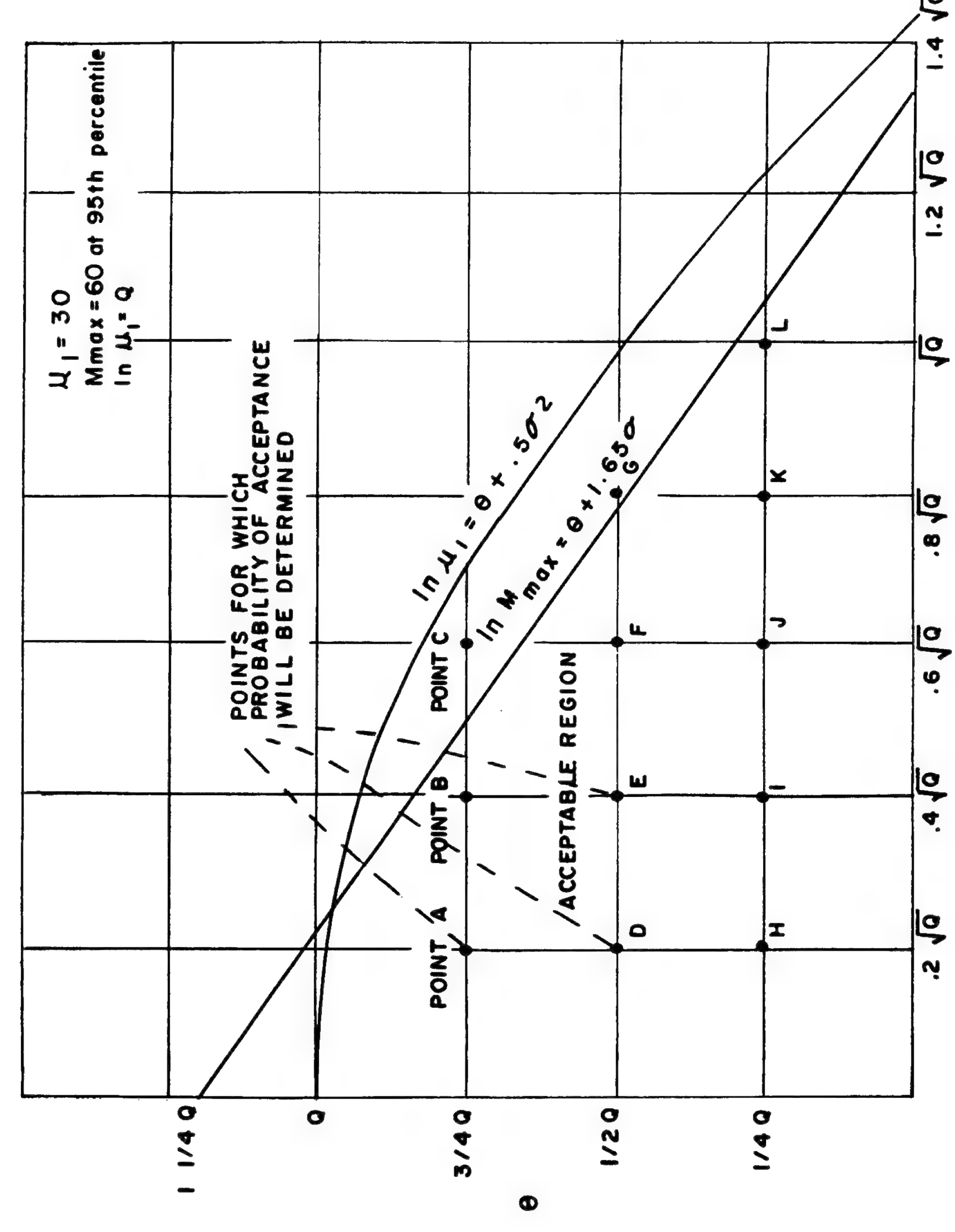

$\mu_1 = 30$
Mmax = 60 at 95th percentile
$\ln \mu_1 = Q$
POINTS FOR WHICH
PROBABILITY OF ACCEPTANCE
WILL BE DETERMINED
$\ln \mu_1 = \theta + .5\sigma^2$
$\ln M_{max} = \theta + 1.65\sigma$
ACCEPTABLE REGION
POINT A
POINT B
POINT C
D
E
F
G
H
I
J
K
L
1 1/4 Q
Q
3/4 Q
1/2 Q
1/4 Q
θ
$.2\sqrt{Q}$
$.4\sqrt{Q}$
$.6\sqrt{Q}$
$.8\sqrt{Q}$
$\sqrt{Q}$
$1.2\sqrt{Q}$
$1.4\sqrt{Q}$
σ

Figure B-8D

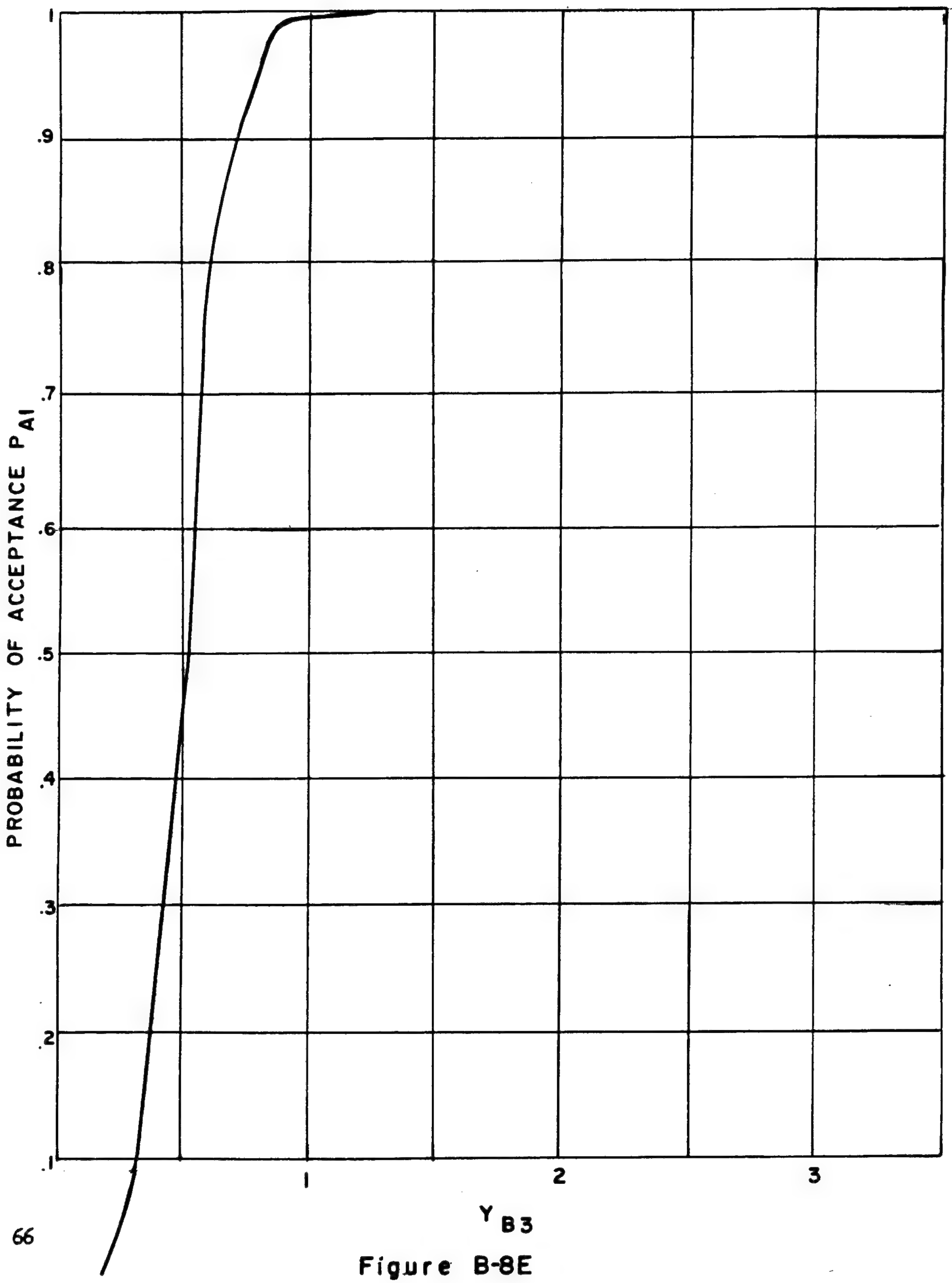


Figure B-8E

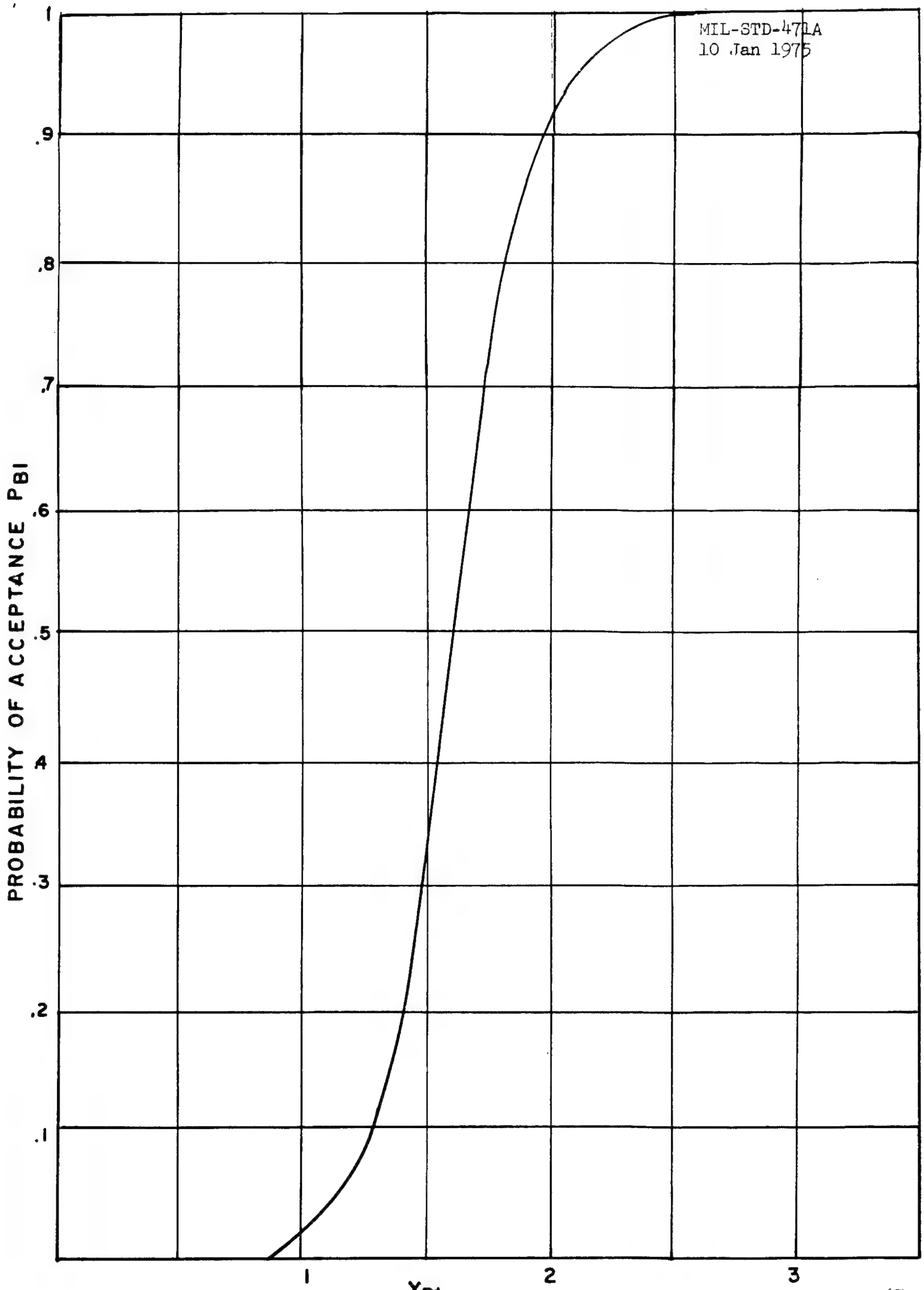


Figure B-8F

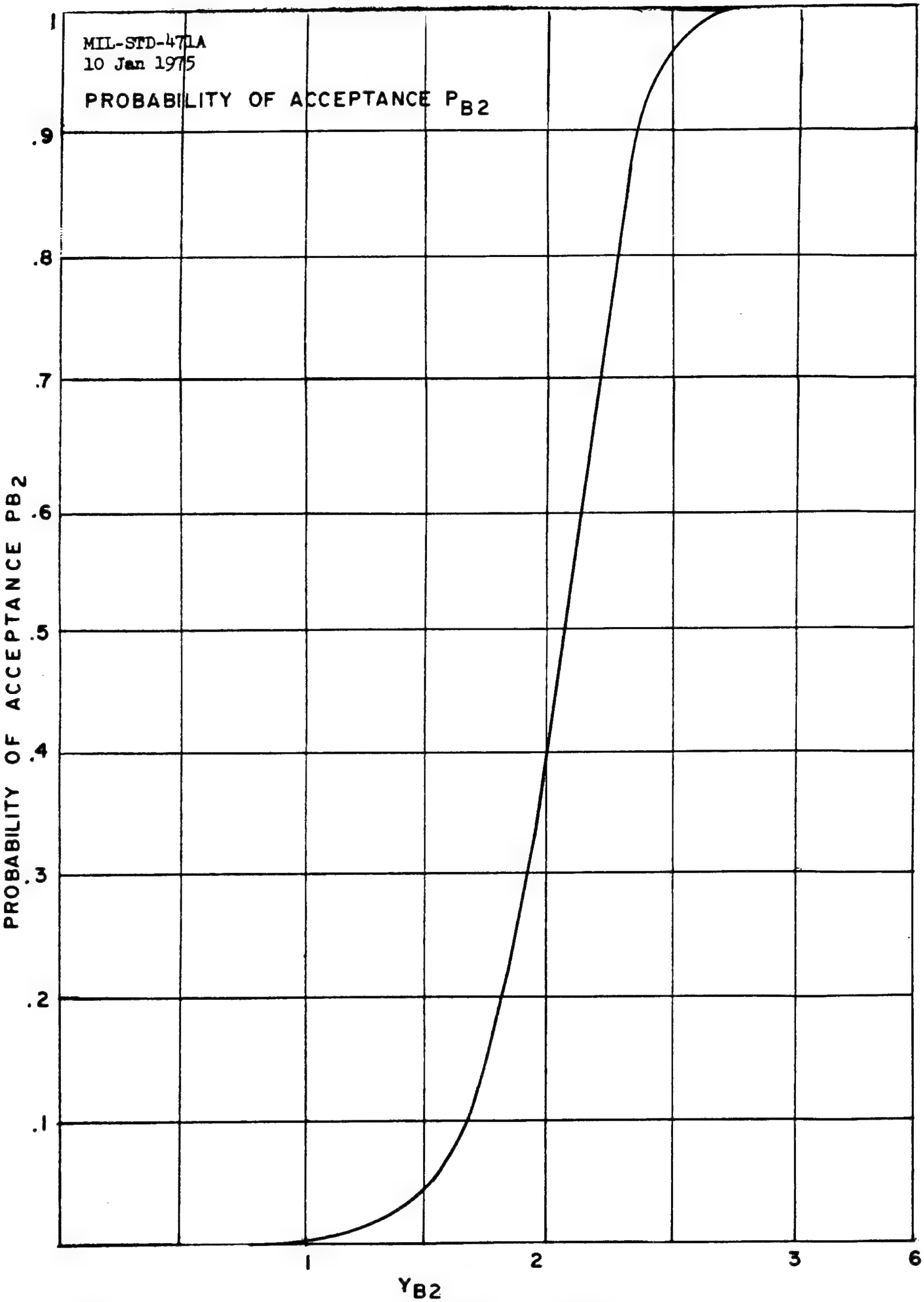

PROBABILITY OF ACCEPTANCE P_{B2}
1
.9
.8
.7
.6
.5
.4
.3
.2
.1
PROBABILITY OF ACCEPTANCE P_{B2}
1
2
3
6
Y_{B2}

Figure B-8G

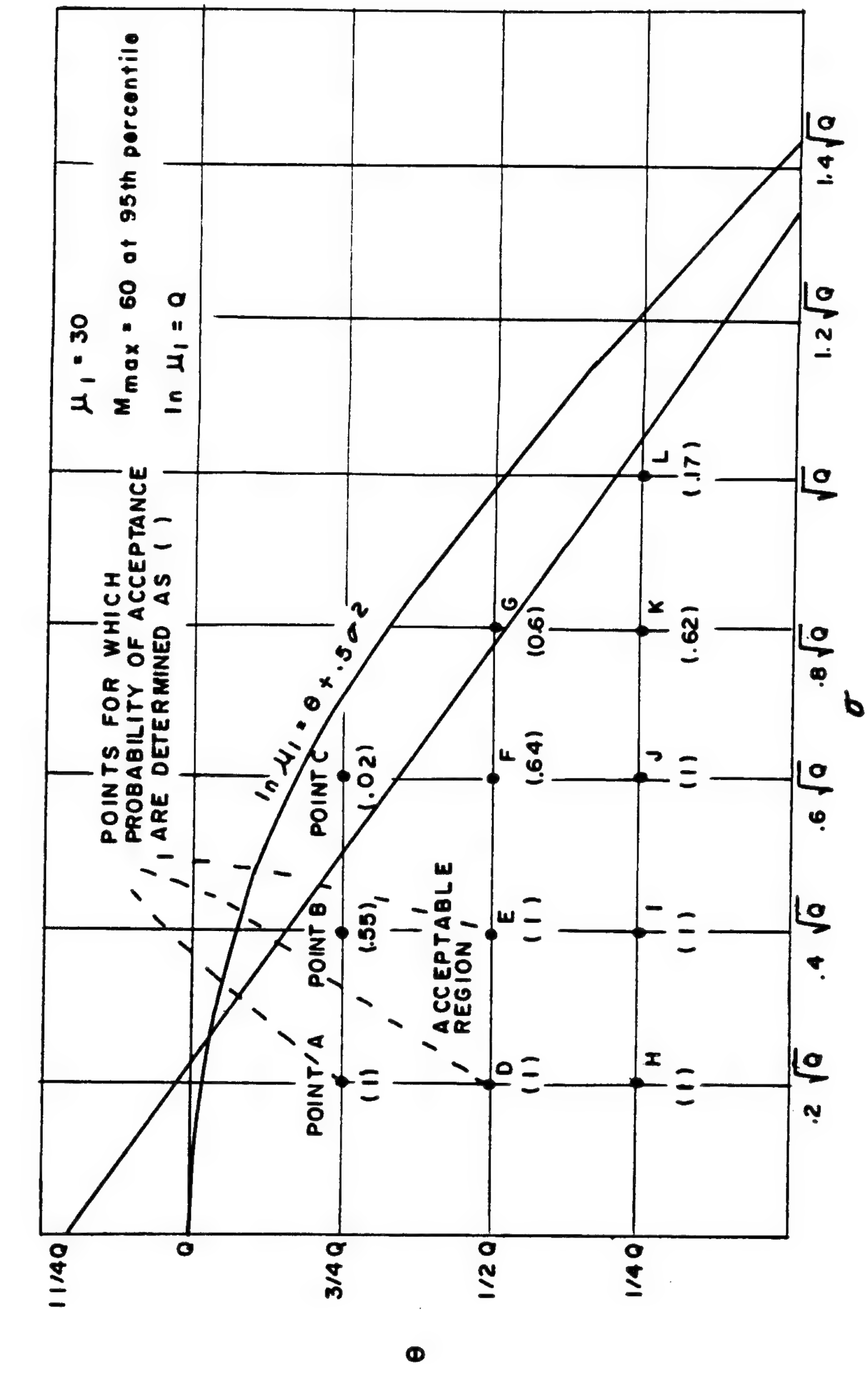

μ1 = 30
Mmax = 60 at 95th percentile
ln μ1 = Q
POINTS FOR WHICH PROBABILITY OF ACCEPTANCE ARE DETERMINED AS ( )
ln μ1 = θ + .5σ2
POINT A
POINT B
POINT C
(1)
(.55)
(.02)
ACCEPTABLE REGION
D
E
F
G
H
I
J
K
L
(1)
(1)
(.64)
(0.6)
(1)
(1)
(1)
(.62)
(.17)
1 1/4Q
Q
3/4 Q
1/2 Q
1/4 Q
θ
.2 √Q
.4 √Q
.6 √Q
.8 √Q
√Q
1.2 √Q
1.4 √Q
σ

Figure B-8H

Test Method 9

TEST FOR MEAN MAINTENANCE TIME (CORRECTIVE PREVENTATIVE COMBINATION OF CORRECTIVE AND PREVENTATIVE) AND M_{MAX}

B100. General - This method is applicable to demonstration of the following indices of maintainability: Mean Corrective Maintenance Time (μ_c), Mean Preventive Maintenance Time (μ_{pm}), Mean Maintenance Time (includes preventive and corrective maintenance actions) ($\mu_{p/c}$), and M_{max} (percentile of repair time).

B100.1 Conditions of Use - The procedures of this method for demonstration of μ_c, are based on the Central Limit Theorem. No information relative to the variance (d^2) of maintenance times is required. It may therefore be applied whatever the form of the underlying distribution, provided the sample size is adequate. The minimum sample size is set at 30. The actual sample size (if greater than 30 are required) shall be determined for each equipment to be demonstrated, and shall be approved by the procuring activity.

The procedure of this method for demonstrating M_{max_c} is valid for those cases where the underlying distribution of corrective maintenance task times is lognormal.

B100.2 Quantitative Requirements - Application of this plan requires identification of the index or indices of interest and specification of quantitative requirements for each. When demonstration involves μ_c or μ_{pm}, or a combination of both, consumer's risks will be specified. When demonstration involves M_{max_c}, the percentile point which defines the specified value of M_{max_c} will be specified. A minimum sample size of 30 corrective maintenance tasks is required for demonstration of corrective maintenance indices. A minimum sample of 30 preventive maintenance tasks is required where demonstration of preventive maintenance indices by sampling is permitted and is to be accomplished by this method.

B100.3 Task Selection and Performance - Sample tasks shall be selected in accordance with the procedure outlined in Appendix "A." The duration of each shall be recorded and used to compute the following statistics:

$$\bar{X}_c = \frac{\sum_{i=1}^{n_c} X_{ci}}{n_c}$$

$$\bar{X}_{pm} = \frac{\sum^{n_{pm}} X_{pmi}}{n_{pm}}$$

$$D_t = f_c \bar{X}_c + f_{pm} \bar{X}_{pm}$$

$$\bar{X}_{p/c} = \frac{f_c X_c + f_p X_{pm}}{f_c + f_{pm}}$$

$$M'_{max_c} = \underset{(\text{Base } e)}{\text{Antilog}} \left[\frac{\sum_{i=1}^{n_c} \ln X_{ci}}{n_c} + \Psi \sqrt{\frac{\sum_{i=1}^{n_c} (\ln X_{ci})^2 - \frac{\left(\sum_{i=1}^{n_c} \ln X_{ci}\right)^2}{n_c}}{n_c - 1}} \right]$$

Where Ψ is the value of the independent variable log-normal function which corresponds to the percentile point at which M_{max_c} has been established. For the two most common percentile points, 90% and 95%, Ψ is 1.282 and 1.645 respectively.

B.100.4 Accept/Reject Criteria - A table of the normal distribution function shall be consulted for values of ϕ (for a one-tail test) which corresponds to the specified level of consumer risk β. The following table provides values of ϕ which correspond to the most commonly used values of β.

TABLE V
ϕ Vs. β

ϕ	β
0.84	20%
1.04	15%
1.28	10%
1.65	5%

Accept/reject criteria shall be computed for each specified index in accordance with the following sections:

B.100.4.1 Test for Mean Corrective Maintenance Time (μ_c) - The accept/reject value for μ_c is: $\bar{X}_c + \frac{\phi \hat{d}_c}{\sqrt{n_c}}$

$\hat{d}_c$ = Std. deviation of sample of corrective maintenance tasks.

Accept if μ_c (specified) $\geq \bar{X}_c + \frac{\phi \hat{d}_c}{\sqrt{n_c}}$

Reject if μ_c (specified) $< \bar{X}_c + \frac{\phi \hat{d}_c}{\sqrt{n_c}}$

B.100.4.2 Test for Mean Preventive Maintenance Time (μ_{pm}) - The accept/reject value for μ_{pm} is: $\bar{X}_{pm} + \frac{\phi \hat{d}_{pm}}{\sqrt{n_{pm}}}$

$\hat{d}_{pm}$ = Std. deviation of preventive maintenance tasks.

Accept if μ_{pm} (specified) $\geq \bar{X}_{pm} + \frac{\phi \hat{d}_{pm}}{\sqrt{n_{pm}}}$

Reject if μ_{pm} (specified) $< \bar{X}_{pm} + \frac{\phi \hat{d}_{pm}}{\sqrt{n_{pm}}}$

B.100.4.3 Test for the Mean of all Maintenance Actions ($\mu_{p/c}$) - The accept/reject value of $\mu_{p/c}$ is:

$$\bar{X}_{p/c} + \phi \sqrt{\frac{n_{pm}\,(f_c\,\hat{d}_c)^2 + n_c\,(f_{pm}\,\hat{d}_{pm})^2}{n_c\,n_{pm}\,(f_c + f_{pm})^2}}$$

If $\mu_{p/c}$ (specified) $\geq \bar{X}_{p/c} + \phi \sqrt{\frac{n_{pm}\,(f_c\,\hat{d}_c)^2 + (f_{pm}\,\hat{d}_{pm})^2}{n_c\,n_{pm}\,(f_c + f_{pm})^2}}$ Accept

If $\mu_{p/c}$ (specified) $< \bar{X}_{p/c} + \phi \sqrt{\frac{n_{pm}\,(f_c\,\hat{d}_c)^2 + n_c\,(f_{pm}\,\hat{d}_{pm})^2}{n_c\,n_{pm}\,(f_c + f_{pm})^2}}$ Reject

B.100.4.4 Test for M_{max} - The accept/reject value for M_{max_c} is:

$$M'_{max_c} = \begin{matrix}\text{Antilog} \\ \text{(Base e)}\end{matrix} \left[\frac{\sum_{i=1}^{n_c} (\ln X_{ci})}{n_c} + \psi \sqrt{\frac{\sum_{i=1}^{n_c} (\ln X_{ci})^2 - \frac{\left(\sum_{i=1}^{n_c} \ln X_{ci}\right)^2}{n_c}}{n_c - 1}} \right]$$

Accept if M_{max_c} (specified) $\geq M'_{max_c}$

Reject if M_{max_c} (specified) $< M'_{max_c}$

Test Method 10

TESTS FOR PERCENTILES AND MAINTENANCE TIME (CORRECTIVE PREVENTATIVE MAINTENANCE)

B110. General - This method employs a test of proportion to demonstrate achievement of $\tilde{M}_{ct}$, $\tilde{M}_{pm}$, M_{max_c} and $M_{max_{pm}}$ when the distribution of corrective and preventive maintenance repair times is unknown.

B110.1 Conditions of Use - This method is intended for use in cases where no information is available on the underlying distribution of maintenance task times. The plan holds the confidence level at 75% or 90% as may be desired and requires a minimum sample size (N) of 50 tasks.

B110.2 Quantitative Requirements - Application of this method required specification of $\tilde{M}_{ct}$, $\tilde{M}_{pm}$, $M_{max_{ct}}$ (95th percentile) or $M_{max_{pt}}$ (95th percentile) and selection of 75% or 90% confidence level.

B110.3 Task Selection and Performance - Sample tasks shall be selected in accordance with the proceudres of Appendix "A." The duration of each task will be compared to the required value(s) of the specified index or indices ($\tilde{M}_{ct}$, $\tilde{M}_{pm}$, $M_{max_{ct}}$ and $M_{max_{pm}}$) and recorded as greater than or lesser than each index.

B110.4 Accept/Reject Criteria - The item under test shall be accepted when the number of observed task times which exceed the required value of each specified index is less than or equal to that shown in the Table (B-10A or B-10B) corresponding to each index for the specified confidence level.

B110.4.1 Test for the Median - Table B-10A below is a test of the median for corrective and preventive maintenance tasks. The acceptance level is shown for two confidence levels and a sample size (N) of 50 tasks.

Table B-10A

Acceptance Table for $\tilde{M}_{ct}$ or $\tilde{M}_{pm}$

Sample size = 50

Confidence Level	
75%	90%
Acceptance Level	
22	20

B110.4.2 Test for M_{max_c} and $M_{max_{pm}}$ - Table B-10B is a test for M_{max_c} and $M_{max_{pm}}$ at the 95th percentile. The acceptance level is shown for two confidence levels and a sample size (N) of 50 tasks.

Table B-10B

Acceptance Table for $M_{max_{ct}}$ or $M_{max_{pm}}$

Sample size = 50

Confidence Level	
75%	90%
Acceptance Level	
1	0

NOTE: Reference - "Introduction to Statistical Analysis" by Dixon & Massey, Page 230, McGraw-Hill Company, 2nd Edition, 1957.

Test Method 11

TEST FOR PREVENTATIVE MAINTENANCE TIMES

B.120 General - This method provides for maintainability demonstration when the specified index involves μ_{pm} and/or $M_{max_{pm}}$ and when all possible preventive maintenance tasks are to be performed.

B.120.1 Conditions of use - All possible tasks are to be performed and no allowance need be made for underlying distribution.

B.120.2 Quantitative requirements - Application of this plan requires quantitative specification of the index or indices of interest. In addition, the percentile point defining $M_{max_{pm}}$ must be stipulated when $M_{max_{pm}}$ is of interest.

B.120.3 Task selection and performance - All preventive maintenance tasks will be performed. The total population of PM tasks will be defined by properly weighing each task in accordance with relative frequency of occurrence as follows: Select the particular task for which the equipment operating time to task performance is greatest and establish that time as the reference period. Determine the frequency of occurrence (f_{pm}) of all other tasks during the reference period. Where the frequency of occurrence of a given task is a fractional number, the frequency shall be set at the nearest integer. The total population of tasks consists of all tasks with each repeated in accordance with its frequency of occurrence during the reference period.

B.120.4 Accept/reject criteria -

B.120.4.1 Test for μ_{pm} - the mean shall be computed as follows:

$$\mu_{pm}\,(\text{Actual}) = \frac{\sum_{i=1}^{k} f_{pmi}\,(X_{pmi})}{\sum_{i=1}^{k} f_{pmi}}$$

Where: f_{pmi} is the frequency of occurrence of the i^{th} task in the reference period.

k is the number of different PM tasks.

Σf_{pmi} is the total number of PM tasks in the population.

Accept if: $\mu_{pm}\,(\text{required}) \geq \mu_{pm}\,(\text{actual})$

Reject if: $\mu_{pm}\,(\text{required}) < \mu_{pm}\,(\text{actual})$

B.120.4.2 Test for $M_{max_{pm}}$ - The PM tasks shall be ranked by magnitude (lowest to highest value). The equipment shall be accepted if the magnitude of the task time at the percentile of interest is equal to or less than the required value of $M_{max_{pm}}$.

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MIL-STD-471A
INTERIM NOTICE 2 (USAF)
8 December 1978

MAINTAINABILITY VERIFICATION/DEMONSTRATION/EVALUATION

This limited coordination change notice is approved for use by all Departments of the Air Force, and is available for use by all Departments and Agencies of the Department of Defense.

The attached addendum is to be added to MIL-STD-471A.

Reviewer - 13

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Air Force - 17

Project MISC-FD14

DEMONSTRATION AND EVALUATION OF EQUIPMENT/SYSTEM BUILT-IN-TEST/EXTERNAL TEST/FAULT ISOLATION/TESTABILITY ATTRIBUTES AND REQUIREMENTS

1. SCOPE

1.1 Purpose: This addendum to MIL-STD-471A provides procedures for the evaluation and demonstration of equipment/system Built-in-Test (BIT) and external test subsystem Fault Isolation and Testability attributes which relate to maintainability and various logistic support factors which are impacted by maintainability. Its purpose is to supplement the more conventional maintainability test requirements (which deal with accessibility, time, and human factors) with tests appropriate to Built-in-Test, External Test, and Fault Isolation capabilities of the system or subsystem in question.

1.2 Application: This addendum is intended for use when evaluation and demonstration of BIT and external test subsystem (tester) Fault Isolation, and Testability attributes and requirements for hardware procurement is required. It provides evaluation and demonstration procedures for use at the equipment/system Operational (organizational) Level, at the Shop Maintenance Level and the Depot Maintenance Level. Such demonstrations shall be called out as a separate part of the maintainability program and may be performed independently of the tests called out in other portions of MIL-STD-471. Such demonstrations shall generally precede conventional maintainability demonstrations contained in other portions of MIL-STD-471A.

2.0 DEFINITIONS

Initial Isolation: Isolation to the equipment/system subunit which must be replaced on line to return the equipment/system to operation. A subunit can be a modular assembly, a printed circuit card which is part of a non-removable drawer, or a component such as a crystal or antenna subsection. In the event that the maintenance concept requires a subunit to be removed,

repaired and then replaced in the equipment/system, initial isolation includes both isolation to the failed subunit and isolation to the failed and removable portion of the subunit.

Initial Isolation Level of Ambiguity: The number of possible equipment/system subunits, as defined above, identified by the Built-in-Test, external test equipment, or manual test procedure, which might contain the failed component. It is possible that a combination of Built-in-Test, external special purpose test equipment, and manual procedures may be necessary to effect isolation. For example, if an equipment test subsystem (Built-in, external, manual) isolates a fault to one of two subunits, the level of ambiguity is equal to two; if it isolates it to one of three subunits the level of ambiguity is equal to three.

Secondary Isolation: Isolation to the subunit component/part which must be replaced in the shop to return the subunit to serviceable condition. The subunit component/part can be a modular assembly, a printed circuit card, or a piece part. In the event that Initial Isolation Level of Ambiguity necessitates the removal and replacement of two or more subunits (only one of which has malfunctioned) Secondary Isolation includes both isolation to the actual failed subunit (after removal from the system/equipment) and isolation to the component/part in the failed subunit.

Secondary Isolation Level of Ambiguity: The number of possible subunit components/parts as defined above, identified by Built-in-Test, external testers or manual test procedures, which might contain the failed component/part (it is possible that a combination of Built-in-Test, external testers, and manual procedures might be necessary to effect isolation). For example, if a subunit test system (say a tester) isolates the faulty component to one of two printed circuit cards, the level of ambiguity is two, if it isolates to one of three printed circuit cards the level of ambiguity is equal to three.

Tertiary Isolation: Isolation (usually at the depot level) at the lowest replacement level of a subunit or a component/part belonging to a subunit to return the item in question to serviceable condition. The lowest replacement level may constitute a modular assembly, printed circuit card, or a piece part.

Tertiary Isolation Level of Ambiguity: The number of possible item parts (or combinations of item parts), identified by testers, test points, or manual test procedures, which must be replaced (or individually tested and then replaced) to return the item to serviceable condition. In some cases, a combination of parts (more than one part) may be required to return an item to serviceable condition. This isolation level in some instances may have to be evaluated on a qualitative basis as high, medium, or low based on the characteristics of the item, the general test instruments required and the effectiveness of the special instruments and testers available.

Manual Procedures: Any procedure which requires (1) measurements using general purpose test equipment, or (2) a series (more than one) of sequential remove and replace actions on subunits (subunit component/parts), (lowest level replacements internal to subunit component/parts), some of which are non-failed, in order to diagnose and isolate a failed subunit (subunit component/part), (lowest level replacement internal to a subunit component/part).

3. GENERAL PROCEDURE FOR EVALUATION/DEMONSTRATION OF BIT/FAULT ISOLATION/TESTABILITY ATTRIBUTES AND REQUIREMENTS: NOTE: Paragraph A.10.4

of MIL-STD-471A calls for selection of a Sample of Maintenance Tasks (which are to be simulated) equal to four times that required for the actual Maintainability Demonstration. Paragraph A.10.5 of MIL-STD-471A calls for a failure mode selection and a failure modes and effects analyses for all sample tasks. The level to which the failure mode will be chosen is dependent on the scope of the requirement or the particular evaluations of interest. If, for example, the requirement pertained only to Initial Isolation characteristics, just the different failure modes associated with the outputs of the subunits need be considered in the analysis. If the requirement pertains to both Initial and Secondary Isolation characteristics, just the different failure modes associated with the outputs of each subunit's components/parts need be considered in the analysis. If the requirement pertains to Initial, Secondary and Tertiary Isolation characteristics, then the failure modes associated with the outputs of the lowest possible replaceable parts (at the tertiary level) need be considered in the analysis.

Where test or evaluation is to be performed relative to the quality or effectiveness of the fault detection and location capabilities of the equipment/system, the following procedures shall apply:

a. Each sample simulated fault selected in accordance with paragraph A.10.4, A.10.5 and B.10.4 of MIL-STD-471A and contained in Column 11 (see paragraph A.10.4.j) shall be analyzed to determine whether or not a clear indication of equipment/system failure is provided and whether or not such indication occurs in an obvious fashion. This procedure does not require a demonstration of repair of the faults induced.

b. Each simulated fault shall be analyzed to determine the level of

ambiguity which the equipment/system Built-in-Test, external test equipment, or manual test procedures (documented or undocumented in the Technical Orders) performs the initial isolation. Where appropriate, the above analysis shall be performed for Secondary and Tertiary levels of isolation during the test phase. The results of the above shall be depicted in the form of an Equipment/System Testability Profile - See Table 3.

3.1 Development of Equipment/System Testability Profile: The results of the fault analysis shall be presented to the level necessitated by the requirement(s), following the format of Table 3.

a. Column (1) identifies the number of the failure simulated.

b. Column (2a) denotes that the simulated failure is immediately identified as causing an equipment/system failure.

c. Column (2b) denotes that the simulated failure produced manifestations out of the ordinary, but which could not immediately be identified as indicative of equipment/system failure.

d. Column (2c) denotes that the simulated failure was not detected.

e. Column (3a) denotes that Initial Isolation to the failed subunit was accomplished at least partially by Built-in-Test.

f. Column (3b) denotes that Initial Isolation to the failed subunit was accomplished at least partially by external test subystems.

g. Column (3c) denotes that Initial Isolation to the failed subunit was accompished at least partially by manual test procedures, either documented in the Technical Orders or not contained in the Technical Orders.

NOTE#1: It is possible that for any given isolation, two or more of the techniques discussed above (e, f, g) must be used.

h. Column (3d) denotes the ambiguity level associated with the failure.

NOTE#2: The isolation profile for Initial, (Secondary), (Tertiary) Isolation shall be if possible broken down as in the circled portions of Table 3A and as per the following example:

FAILURE NO.	BUILT-IN-TEST	EXTERNAL TEST	MANUAL PROCEDURES	LEVEL AMBIGUITY
1	X			4
1		X		2
1			X	1

In this case, for failure number 1 - the Built-in-Test is capable of isolation to four subunits. External test subsystems are used to reduce the ambiguity further to one of two subunits. Manual test procedures are required to isolate to a single failed unit.

i. Column (4a) denotes that Secondary Isolation to the failed subunit component or part was carried out at least partially with the aid of the equipment/system Built-in-Test or with Built-in-Test associated with the failed unit itself.

j. Column (4b) denotes that Secondary Isolation to the failed subunit component or part was carried out at least partially with the aid of external testers (card testers, special test subystems).

k. Column (4c) denotes that Secondary Isolation to the failed subunit component or part was carried out at least partially by manual

means either documented in the Technical Orders, or not documented in the Technical Orders.

l. Column (4d) denotes the ambiguity level associated with the failure. The isolation table shall if possible be broken down as in Note #2 and its example.

m. Column (5a) denotes that Teritary (depot) Isolation of the failed item(s) was accomplished at least partially by Built-in-Test associated with the item.

n. Column (5b) denotes that Tertiary Isolation of the failed item(s) was accomplished at least partially by special test systems (testers).

o. Column (5c) denotes that Tertiary Isolation of the failed item(s) was accomplished at least partially by manual means, either documented in the Technical Orders or not documented in the Technical Orders.

3.2 Procedure for Development of Equipment Evaluation Profile for Failure Detection and Isolation.

a. For columns 2a-2c for each failure simulated, place an x in the appropriate column.

b. For column 3a, 4a, and 5a for each failure simulated (as in table 3), place an x in the column if Built-in-Test was used for Initial, (Secondary),(Tertiary) Isolation and indicate in corresponding column 3d,(4d),(5d), the ambiguity level resulting from the use of Built-in-Test (if Built-in-Test was not, or could not be used in the

Initial, (Secondary), (Tertiary) Isolation process, leave that part of column 3a, (4a), (5a) blank and leave the corresponding part of column 3d, (4d), (5d) blank).

c. For columns 3b, 4b, and 5b for each failure simulated (as in Table 3), place an x in the column if external test systems or testers were used for Initial, (Secondary), (Tertiary) Isolation and indicate in the corresponding column 3d, (4d), (5d) the ambiguity level resulting from the use of external test systems or testers (if external test systems or testers were not, or could not be used in the Initial, (Secondary), (Tertiary) Isolation process, leave that part of column 3b, (4b), (5b) blank and leave the corresponding part of column 3d, (4d), (5d) blank).

d. For columns 3c, 4c, and 5c for each failure simulated (as in Table 3) place an x in the column if manual means using general purpose test equipment and procedures documented in the Technical Orders were used in the Initial, (Secondary), (Tertiary) Isolation process. Place a zero (o) in the column if manual means using general purpose test equipment and procedures not documented in the Technical Orders were used to perform Initial, (Secondary), (Tertiary) Isolation. It is possible to have both an x and a zero (o) entry in the same part of the column (which denotes that both documented and undocumented procedures were necessary to effect isolation). The corresponding column 3d, (4d), (5d) should be made to indicate the resulting ambiguity level.

e. For columns 3d and 4d, as described above.

f. For column 5d, indicate in the corresponding place in column 5d the ambiguity level resulting (high, medium, low) from each entry in 5a, 5b and 5c.

4. <u>USE OF THE EQUIPMENT EVALUATION PROFILE FOR EVALUATION AND TEST PURPOSES</u>: Using the information compiled on the profile, data can be computed pertinent to the following testability attributes (Figures of Merit) which can be used either for evaluation or demonstration purposes.

P_a^1 = Proportion of Sample Failures detected.

$$P_a^1 = \frac{\text{number of x's in column 2a}}{\text{total number of failures simulated}}$$

For example $P_a^1 = .8$ would indicate that 80% of the sample failures were detected.

P_{1B}^1, (P_{2B}^1), (P_{3B}^1) = Proportion of sample failures for which Built-in-Test (BIT) and/or special purpose external test systems (SPETS) are effective to <u>reduce</u> ambiguity for Initial Isolation, (Secondary Isolation), (Tertiary Isolation).

$$P_{1B}^1, (P_{2B}^1), (P_{3B}^1) = \frac{\text{number of failures for which BIT and/or SPETS reduce Initial, (Secondary), (Tertiary) Isolation Ambiguity}}{\text{Total Number of Failures Simulated}}$$

For example, $P_{1B}^1 = .9$ indicates that for 90% of all sample failures either BIT or SPETS or BOTH IN COMBINATION were effective in reducing ambiguity during Initial Isolation.

L_{1a}, (L_{2a}), (L_{3a}) = Average resulting ambiguity level associated with the use of Built-in-Test (BIT) and/or special purpose external test systems (SPETS) for Initial Isolation, (Secondary Isolation), (Tertiary Isolation).

$$L_{1a}, (L_{2a}), (L_{3a}) = \frac{\sum^{S} L_{ai}}{S}$$

where

L_{ai} = lowest value of ambiguity associated with the use of BIT and/or SPETS for the i^{th} failure in order to effect Initial, (Secondary), (Tertiary) Isolation.

S = Total number of failures which employ either BIT or SPETS or both to effect Initial,(Secondary), (Tertiary) Isolation.

For example an $L_{1a} = 3$ in conjunction with a $P_1{}^1{}_B = .9$ would indicate that for 90% of all failures BIT and/or SPETS are capable of reducing ambiguity, and when this occurs, the associated average level of ambiguity = 3.

$P_{a1}, (P_{a2}), (P_{a3})$ = Proportion of sample failures which require only the use of Built-in-Test (BIT) for Initial Isolation,(Secondary Isolation),(Tertiary Isolation) to a given level of ambiguity or less.

$$P_{a1}, (P_{a2}), (P_{a3}) = \frac{\text{\# of failures requiring only BIT to perform Initial, (Secondary), (Tertiary) Isolation to a level of ambiguity} \leq L}{\text{Total number of failures simulated}}$$

For example, $P_{a1} = .6$ and $L = 3$ would indicate (for Initial Isolation) that for 60% of all failures, Built-in-Test is capable of isolating failures to one of three subunits or better.

$P_{b1}, (P_{b2}), (P_{b3})$ = Proportion of sample failures which requires only the use of special purpose test systems (SPETS) for Initial Isolation, (Secondary Isolation), (Tertiary Isolation) to a given level of ambiguity or less.

$$P_{b1}, (P_{b2}), (P_{b3}) = \frac{\text{\# of failures which require only SPETS for Initial, (Secondary), (Tertiary) Isolation to ambiguity level} \leq L.}{\text{Total number of failures simulated}}$$

For example a P_{b2} = .5 for an L=1 would indicate (for a subunit comprised of printed circuit cards) that only half of the failures could be isolated to a single printed board by the special testers provided.

P_{c1}, (P_{c2}), (P_{c3}) = Proportion of sample failures which require some degree of Manual Testing (documented in Technical Orders) to effect Initial Isolation, (Secondary Isolation), (Tertiary Isolation).

$$P_{c1}, (P_{c2}), (P_{c3}) = \frac{\text{number of x's in column 3c, (4c), (5c)}}{\text{Total number of failures simulated}}$$

For example P_{c1} = .2 would indicate that 20% of all sample failures required the application of manual test procedures (documented in the Technical Orders) in order to effect Initial Isolation.

P_{d1}, (P_{d2}), (P_{d3}) = Proportion of sample failures which require some degree of Manual Testing (<u>NOT</u> documented in Technical Orders) to effect Initial Isolation, (Secondary Isolation), (Tertiary Isolation).

$$P_{d1}, (P_{d2}) (P_{d3}) = \frac{\text{number of zeros in column 3c, (4c), (5c)}}{\text{Total number of failures simulated}}$$

For example P_{d1} = .1 would indicate that 10% of all sample failures required the application of manual test procedures, <u>not</u> documented in the Technical Orders, in order to effect Initial Isolation.

P_{e1}, (P_{e2}), (P_{e3}) = Proportion of sample failures for which Built-in-Test (BIT) and/or special purpose external test systems (SPETS) are capable of effecting Initial Isolation, (Secondary Isolation), (Tertiary Isolation) to a <u>given</u> level of ambiguity or better.

$$P_{e1}, (P_{e2}), (P_{e3}) = \frac{\text{\# failures requiring either BIT or SPETS or both for Initial, (Secondary), (Tertiary) Isolation to ambiguity level} \leq L}{\text{Total number of failures simulated}}$$

For example a P_{e1} = .6 and an L = 2 would indicate that for 60% of all failures, BIT or SPETS or any combination thereof, is capable of effecting Initial Isolation to one of two subunits or better.

P_{F1}, (P_{F2}), (P_{F3}) = Proportion of sample failures for which Built-in-Test is effective in Initial Isolation, (Secondary Isolation), (Tertiary Isolation) in reducing ambiguity.

$$P_{F1}, (P_{F2}), (P_{F3}) = \frac{m}{\text{Total number of failures simulated}}$$

where

m = Number of simulated failures in which Initial, (Secondary), (Tertiary) Isolation takes place (ambiguity is reduced) at least partially through the use of Built-in-Test = number of x's in column 3a, (4a), (5a).

For example a P_{F1} = .7 indicates that Built-in-Test is effective to some extent in removing ambiguity during Initial Isolation for 70% of all failures.

P_{g1}, (P_{g2}), (P_{g3}) = Proportion of sample failures for which special purpose external test systems are effective in Initial Isolation, (Secondary Isolation), (Tertiary Isolation) in reducing ambiguity.

$$P_{g1}, (P_{g2}), (P_{g3}) = \frac{K}{\text{Total number of failures simulated}}$$

where

K = Number of simulated failures in which Initial, (Secondary), (Tertiary) Isolation takes place (ambiguity reduced) at least partially through the use of special purpose external test systems. = number of x's in column 3b, (4b), (5b).

For example a P_{g2} = .8 applied to a subunit comprised of printed circuit cards would indicate that the special purpose external test system (say a TESTER) is effective to some extent in removing ambiguity during Secondary Isolation for 80% of all failures.

L_{b1}, (L_{b2}), (L_{b3}) = Average resulting ambiguity level for Built-in-Test when used for Initial Isolation, (Secondary Isolation), (Tertiary Isolation).

$$L_{b1}, (L_{b2}), (L_{b3}) = \frac{\sum_{i=1}^{m} L_{bi}}{m}$$

m = Number of simulated failures in which Initial, (Secondary), (Tertiary) Isolation takes place (ambiguity is reduced) at least partially through the use of Built-in-Test. = number of x's in column 3a, (4a), (5a).

L_{bi} = Ambiguity level associated with the ith simulated failure after using Built-in-Test at least partially to effect Initial, (Secondary), (Tertiary) Isolation.

This indicates for example in the case of Initial Isolation, that the functional Built-in-Test features of the equipment will on the average isolate to L_{b1} different subunits. Taken in conjunction with the $P_{F1} = .8$ it indicates that: For 80% of all failures Built-in-Test performs isolation and when it does, its average level = L_{b1}.

L_{c1}, (L_{c2}), (L_{c3}) = Average resulting ambiguity level for special purpose external test systems when used for Initial Isolation, (Secondary Isolation), (Tertiary Isolation).

$$L_{c1}, (L_{c2}), (L_{c3}) = \frac{\sum_{i=1}^{K} L_{ci}}{K}$$

L_{ci} = Ambiguity level associated with the ith simulated failure after using external special purpose test systems or testers to effect Initial, (Secondary), (Tertiary) Isolation.

K = Number of simulated failures in which Initial, (Secondary), (Tertiary), Isolation takes place at least partially through the use of external special purpose test systems or testers. = number of x's in column 3b, (4b), (5b).

For example, an L_{c2} = 2 related to Secondary Isolation would indicate that on the average when special purpose test equipment or testers are used in Secondary Isolation, they on the average perform isolation down to a level of ambiguity = 2. Taken in conjunction with a P_{g2} = .8 it indicates that 80% of all Secondary Isolation is performable with special purpose test equipment and on the average that test equipment isolates to ambiguity level = 2.

5. CONFIDENCE LEVELS FOR TESTABILITY ATTRIBUTES: The parameters dealing with proportion (P_{a1}, P_{b1}, etc.) as described in the previous paragraph represent observed estimates, based upon sampling of the actual proportions in question. For evaluation purposes, it is usually necessary to define the probable range of the actual equipment/system proportions from the results of sampling. The following procedure defines an approach to this end.

$$P_{ULC} = P \pm Z_c \sqrt{\frac{P(1-P)}{W}}$$

P_{ULC} = The upper and lower bounds of the actual value of proportion for a given confidence interval.

P = The observed estimate of proportion from the sample.

W = The sample size from which P is computed.

Z_c = A co-efficient dependent on the confidence interval desired.

The following table provides appropriate values of Z_c for various confidence intervals:

Z_c	Confidence Interval
1.28	80%
1.65	90%
1.96	95%

5.1 Treatment of the Values of L (i.e., L_{1a}, L_{b1}, L_{c1}, etc.)

For evaluation purposes, values of L will be treated as point estimates as in paragraph 4.

6. DEMONSTRATION FOR TESTABILITY ATTRIBUTES (VALUES OF P): For those instances where the parameters dealing with proportion (P_{1a}, P_{b1}, P_{c1}, etc.) as described in paragraph 4, have been levied as specification requirements and must be demonstrated, the following procedures will apply:

- Case (A) for situations where the higher the value cf P, the better the Testability of the equipment/system.

  (i.e., P^1_a, P^1_{2b}, P_{a1}, P_{b1}, etc.)

  Accept if

  $$P \geq P_s - 1.28\sqrt{\frac{P(1-P)}{W}}$$

  Reject otherwise

- Case (B) for situations where the lower the value of P, the better the Testability of the equipment/system, i.e., P_{c1}, P_{d1}, etc.

  Accept if

  $$P \leq P_s + 1.28\sqrt{\frac{P(1-P)}{W}}$$

  Reject otherwise

These tests provide the producer with a 10% risk of rejection (1.28 is the coefficient of the normal distribution which yields this risk) and at the same time provide the consumer assurance that testability designs with significant deviations from specified values will be rejected.

Where P = measured testability proportion from sample.

P_s = specified proportion.

W = the sample size from which P is computed.

6.1 Demonstration for Values of L (i.e., L_{1a}, L_{b1}, L_{c1}, etc.):

For demonstration purposes, values of L will be as estimated in paragraph 4.

6.2 Validation of Data used for Evaluation/Demonstration:

In order to validate the accuracy of the data contained in the testability profile and hence, determine its acceptability, the following procedure will apply:

a. The observed diagnostic and fault isolation characteristics of the sample population of failures induced for maintainability demonstration (see paragraph A.10.4.1k of MIL-STD-471A) shall be documented in the format of Table 3.

b. The data above shall be compared with the data related to the same simulated faults contained in the testability profile.

c. If 90% or more of the simulated faults used in the maintainability demonstration show the same profile results as depicted in the testability profile for those same faults the profile is considered acceptable.

In the event that the testability profile was generated totally from actual hardware tests in the presence of representatives of the procuring activity, the profile will be considered valid without recourse to the above.

7. FALSE ALARM RATE EVALUATION/DEMONSTRATION: False Alarm Rate, defined in terms of average number of false alarms/24 hour period of equipment or system operating time (λ_F), may be evaluated and demonstrated from false alarm data resulting from controlled tests (i.e., reliability demonstration tests, operational tests, performance tests) subject to procuring activity surveillance. The contractor and representatives of the procuring activity shall jointly determine the specific data sources to be utilized. The contractor shall prepare a plan submitted as part of the Maintainability Demonstration Plan (and subject to Procuring Activity approval) defining the procedures to be

utilized in the collection and documentation of such data.

7.1 Procedures Necessary for Demonstration or Evaluation: A cumulative equipment/system period of operating time(s) (T) must be determined over which the demonstration or evaluation will take place. The cumulative period of operating time (T) must as a minimum, include the operating time duration of the reliability demonstration test(s). When the evaluation or demonstration of False Alarm Rate is to be terminated prior to operational field use testing, the demonstration/evaluation shall be considered terminated at the end of contractor reliability demonstration.

When evaluation/demonstration has been terminated, the following calculations are performed:

A. Let expected number of false alarms = $\frac{\lambda_{FS}T}{24}$

where

λ_{FS} = the specified average number of false alarms/24 hour period of equipment or system operating time.

T = the cumulative period of equipment or system operating time over which the demonstration or evaluation will take place.

B. Determine from data available the total number of false alarms observed.

7.1.1 For Demonstration Purposes: Go to Figure B1-A and determine the intercept of the Expected Number of False Alarms and the Actual Number of False Alarms Experienced.

A. If the intercept lays in the accept range, the confidence level is approximately 75% or better that the equipment or system meets or betters the False Alarm Rate requirement and the false alarm rate is deemed satisfactory.

B. If the intercept lays in the reject range (or if at any time during the test period it becomes evident that rejection will occur) the false alarm rate is deemed unsatisfactory and the equipment/system is rejected. In order to be

deemed acceptable after rejection, the following procedures will be adhered to:

(1) Analyses of the fault detection/isolation system or unit must be performed to find and correct the design deficiencies which result in the unacceptably high false alarm rate. The contractor shall provide the procuring activity information detailing the results of the above analyses and the steps to be undertaken to correct the deficiencies.

(2) The procuring activity may then:

(a) Accept the equipment on the condition the necessary design changes have been implemented and evidence provided of such implementation, or

(b) Require a new limited test of false alarm rate upon implementation of the necessary design changes prior to final acceptance (this may be integrated or combined with final equipment/system tests).

7.1.2 For Evaluation Purposes: Where it is desired to estimate from the observed data the actual False Alarm Rate to a 75% confidence interval. Go to Figure B1-A and determine the intercept point of the boundary line and the Observed Number of False Alarms. Determine the corresponding Expected Number of False Alarms value at that point. The following relationship will provide the assessment of actual false alarm rate to the confidence desired:

$$\lambda_F = \frac{24(\text{Expected Number False Alarms Value})}{T}$$

where

λ_F = the average number of false alarms/24 hour period of operation.

T = as defined previously.

	FAILURE DETECTED			INI
	YES		NO	
COL. 1	COL. 2A	COL. 2B	COL. 2C	COL. 3A
Failure Number	Immediately	Some Indication but not Immediate Determination		Built-in-Test
1				
1				
1				
2				
2				
2				
3				
3				
3				
4				
4				
4				
5				
. . . . .				
N-1				
N-1				
N-1				
N				
N				
N				

1

	INITIAL ISOLATION				SECONDARY	
NO COL. 2C	COL. 3A	COL. 3B	COL. 3C	COL. 3D	COL. 4A	COL.
	Built-in-Test	External Special Test Subsystem	Manual	Level Ambiguity	Built-in-Test	Exte Spec Test

2

SECONDARY ISOLATION				TERTIARY ISOL		
COL. 4A	COL. 4B	COL. 4C	COL. 4D	COL. 5A	COL. 5B	C(
Built-in-Test	External Special Testers	Manual	Level Ambiguity	Built-in-Test	External Special Testers	Ma

	TERTIARY ISOLATION			
COL. 4D	COL. 5A	COL. 5B	COL. 5C	COL. 5D
Level Ambiguity	Built-in-Test	External Special Testers	Manual	Level Ambiguity

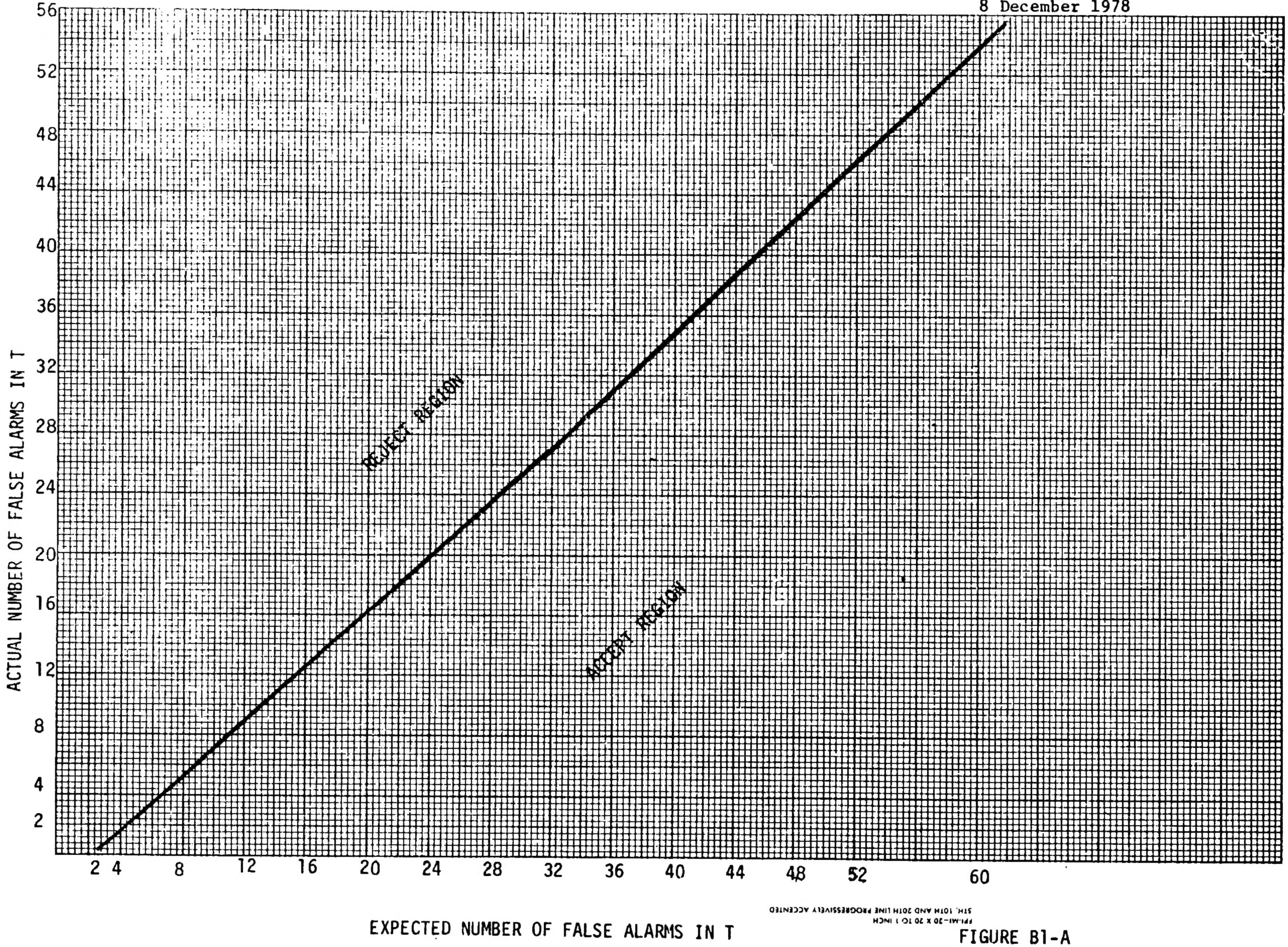
ACTUAL NUMBER OF FALSE ALARMS IN T
56
52
48
44
40
36
32
28
24
20
16
12
8
4
2
REJECT REGION
ACCEPT REGION
2
4
8
12
16
20
24
28
32
36
40
44
48
52
60
EXPECTED NUMBER OF FALSE ALARMS IN T

FIGURE B1-A

EQUIPMENT EVALUATION PROFILE

COL. 1	FAILURE DETECTED YES COL. 2A	COL. 2B	NO COL. 2C	INITIAL ISOLATION COL. 3A	COL. 3B	COL. 3C	COL. 3D	SECONDARY ISOLATION COL. 4A	COL. 4B	COL. 4C	COL. 4D	TERTIARY ISOLATION COL. 5A	COL. 5B	COL. 5C	COL. 5D
Failure Number	Immediately	Some Indication but not Immediate Determination		Built-in-Test	External Special Test Subsystem	Manual	Level Ambiguity	Built-in-Test	External Special Testers	Manual	Level Ambiguity	Built-in-Test	External Special Testers	Manual	Level Ambiguity
1															
1															
1															
2															
2															
2															
3															
3															
3															
4															
4															
4															
. . . .															

TABLE 3A